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Crop Residue Management To Reduce Erosion and Improve Soil Quality

Appalachia and Northeast

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Crop Residue Management Land Resource Regions of the United States

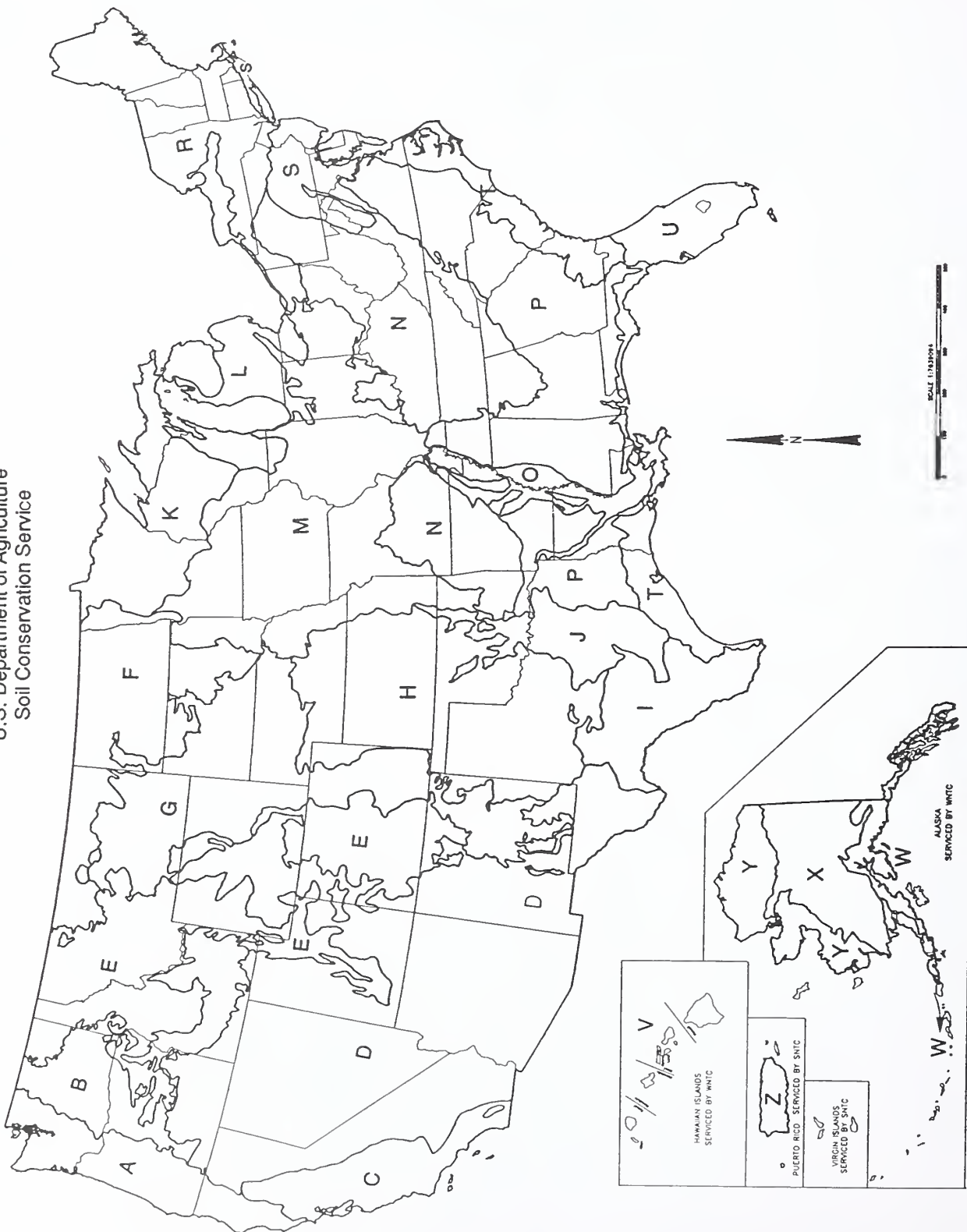
U.S. Department of Agriculture
Soil Conservation Service

Resource Regions and Areas
as of January 1984
Land Resource Regions (LRR)

- | | |
|----------|---|
| A | NW Forest, Forage and Specialty Crops |
| B | NW Wheat and Range |
| C | California Subtropical Fruit, Truck and Specialty Crops |
| D | W. Range and Irrigated |
| E | Rocky Mtn. Range and Forest |
| F | N. Great Plains Spring Wheat |
| G | W. Great Plains Range and Irrigated |
| H | C. Great Plains Winter Wheat and Range |
| I | SW Plateaus and Plains Range and Cotton |
| J | SW Prairies Cotton and Forage |
| K | N. Lake State Forest and Forage |
| L | Lake States Fruit, Truck and Dairy |
| M | Central Feed Grains and Livestock |
| N | East and Central Farming and Forest |
| O | Miss. Delta Cotton and Feed Grains |
| P | S. Atlantic and Gulf Slope Cash Crops, Forest and Livestock |
| R | NE Forage and Forest |
| S | N. Atlantic Slope Diversified Farming |
| T | Atlantic and Gulf Coast Lowland Forest and Crop |
| U | Florida Subtropical Fruit, Truck Crop and Range |
| V | Hawaii |
| W | S. Alaska |
| X | Interior Alaska |
| Y | Arctic and W. Alaska |
| Z | Caribbean Area |

Major Land Resource Areas
(MLRA)
MLRAs and number designation
(see Agriculture Handbook 296)

January 1993 1007614



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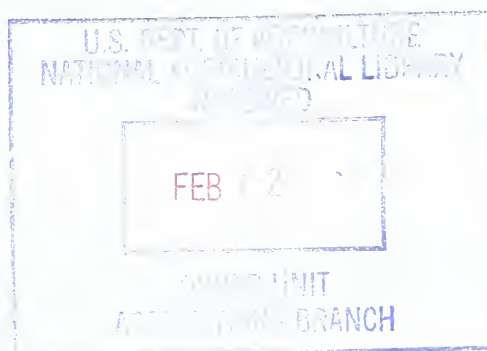
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Crop Residue Management To Reduce Erosion and Improve Soil Quality

Appalachia and Northeast

R.L. Blevins and W.C. Moldenhauer, Editors



Abstract

Blevins, R.L., and W.C. Moldenhauer, eds. 1995. *Crop Residue Management To Reduce Erosion and Improve Soil Quality: Appalachia and Northeast*. U.S. Department of Agriculture, Agricultural Research Service, Conservation Research Report No. 41, 108 pp.

Leaving crop residue on the soil surface has a number of clear advantages over tillage that leaves the soil surface bare. Most notable is the greatly reduced erosion; this advantage alone makes the change worthwhile. Mandated conservation compliance by 1995 is a further incentive to adopt surface-crop-residue management. Other advantages are increased yield due to water conserved by surface residue; lower soil temperatures; higher quality soil over time due to increased soil organic-matter levels; and in many cases, reduced input of time, labor, and fuel.

The feasibility of surface-residue management has been proven by the increasing rate of acceptance and use by farm operators. Success is due in large part to the greater effectiveness and reduced cost of herbicides and the improvement of planting equipment available on the market. Farm operators and conservationists have formed associations and alliances for sharing experiences. Case studies, farmer experiences, and results of research helpful to farm operators have been published by chemical and equipment companies; the farm press; federal, state, and local governmental research and extension agencies; and private organizations.

Keywords: crop residue management (CRM), conservation tillage, reduced tillage, mulch tillage, surface residue tillage, fertilizer management, water quality, soil compaction, soil strength, CRM planting equipment, economics of CRM, soil-climate-tillage interactions in CRM, weed management, herbicides, insect pest management, plant disease management, winter cover crops, tillage long-term effects, erosion control, water-use efficiency

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This publication reports research involving pesticides. It does not contain recommendations for their use or imply that uses discussed here have been registered. All uses of pesticides must be registered by appropriate State or Federal agencies or both before they can be recommended.

While supplies last, single copies of this publication may be obtained at no cost from a local Natural Resources Conservation Service District office. Copies may be purchased from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

This is one of six regional publications designed to report research results and the experience of experts in the field of crop residue management. The other regions are North Central, Northern Great Plains, Northwest, Southeast, and Southern Great Plains. Copies of the five other regional reports for *Crop Residue Management To Reduce Erosion and Improve Soil Quality* may be obtained from Conservation Technology Information Center, 1220 Potter Drive, Room 170, West Lafayette, IN 47906. Payment of postage and handling charges is required (fax 317-494-5969, telephone 317-494-9555).

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1 Introduction: Why the Emphasis on Crop Residue Management?

W.C. Moldenhauer and R.L. Blevins

Soil erosion by wind or water degrades our soils. Besides outrightly removing material from the fertile topsoil, large wind or rain storms selectively remove material that is high in organic matter and nutrients. This results in exposed subsoil that is depleted of plant-available nutrients, is high in density, and has low porosity and capacity for water intake.

Recognizing the rapidity with which U.S. soils were degrading—especially on the 143 million acres of highly erodible lands—Congress passed the Food Security Act in 1985 to conserve our soils and ensure adequate food supplies for future generations. **The act sets a deadline of December 31, 1994, for full implementation of plans to control erosion on highly erodible lands if farmers are to maintain their eligibility for U.S. Department of Agriculture (USDA) program benefits.** When presented with the broad spectrum of available technologies at USDA Natural Resource Conservation Service (NRCS) offices, fully three-fourths of farmers concluded that the most cost-effective means for controlling erosion on their highly erodible lands was to keep more crop residues on the soil surface.

Any tillage and planting system that leaves all or some portion of the previous crop's residue on the soil surface is described as crop residue management by NRCS and the Conservation Technology Information Center, West Lafayette, IN. Surface residue cover is known to greatly reduce soil erosion, even though the percentage required to adequately control erosion depends on the site and other conservation practices included in a total erosion-control system. As residue cover approaches 100 percent, soil erosion approaches zero; with 50 percent residue cover, erosion reduction is about 83 percent; with 10 percent residue cover, erosion reduction is still about 30 percent.

The willingness of farmers to leave residue on the surface was greatly enhanced by the development of herbicides, which provided an alternative to tillage for controlling weeds. The efforts of equipment manufacturers and innovative farmers in developing equipment to leave more residue on the surface and then to plant through it have facilitated the availability and use of crop residue management.

The negative effects of crop residue, once looked on as far outweighing the benefits, are now seen as greatly overestimated, or else solutions have been found to make the negative results manageable. As the scientific, industrial, and farm communities persistently address the problems and find solutions, they approach the remaining problems more as challenges than as insurmountable disadvantages. This

change of attitude has played a major role in accelerating the acceptance of crop residue management.

This is one of six regional reports. Some of the technology is suited specifically to the climate and soils of particular regions. However, due to their recent and rapid development, not all of the potentially useful technologies have been tried in all regions. Consequently, some of the surface-residue management technologies used in other regions and discussed in their reports may apply to Appalachia and the Northeast. Copies of these other regional reports may be obtained from Conservation Technology Information Center (see address and telephone number on abstract page).

Another recent publication that addresses crop residue management with more figures and details is "Conservation Tillage Systems and Management: Crop Residue Management With No-Till, Ridge-Till, Mulch-Till" (1992). It is available from the MidWest Plan Service, 122 Davidson Hall, Iowa State University, Ames, IA 50011-3080 (telephone 1-800-562-3618 to place an order).

This regional report encompasses the following Land Resource Regions: Lake States Fruit, Truck, and Dairy Region (L); East and Central Farming and Forest Region (N); Northeastern Forage and Forest Region (R); and Northern Atlantic Slope Diversified Farming Region (S). These regions are shown on the map in the cover pocket of this report.

The Lake States Fruit, Truck, and Dairy Region (L) borders the Great Lakes and occurs on a glaciated plain that is nearly level to gently sloping. The climate is suited for a wide variety of enterprises, including dairy farming, vegetable and fruit crops, corn, winter wheat, beans, and sugar beets. This region's better drained soils are Udalfs in the southern part and Boralfs in the northern part. Aqualfs and Aquepts are the dominant wet soils, and the more sandy soils are classified as Psamments and Orthods.

The East and Central Farming and Forest Region (N) includes the Appalachian mountains, valleys, and dissected plateaus ranging from the Allegheny plateau in Pennsylvania to Sand Mountain in Alabama. The frost-free period ranges from 140 days in the northeast to 240 days in valleys in southern extremities of the region. More stable Udults and Udalfs are the most extensive upland soils. Ochrepts are extensive on the mountain slopes and dissected plateaus. Limited areas of Udolls occur in limestone valleys and basins. Small general farms are common in much of the region, with larger dairy and livestock farms on the better soils. Hay, corn, soybeans, and small grains are the major crops. Nearly one-half of the region is in forest.

The Northeastern Forage and Forest Region (R) occupies the upper portion of the northeast region from Pennsylvania to Maine. This Land Resource Region has been classified as

a cool, humid region characterized by plateaus, plains, and mountains. Most of the land, particularly the steeper areas, is forested. The frost-free period ranges from 80 days in higher elevations to 200 days along the Atlantic coast. According to Agriculture Handbook 296, the dominant soils are Ochrepts and Orthods and commonly have fragipans. Aqualfs, Aquepts, and Histosols occur in lowlands. Stoniness and steep slopes limit the use of the soils. Forages and grain production for dairy cattle are the major crops in areas where the slope is less limiting. In small areas of this region, the soils, climate, and markets are such that tobacco, fruits, and vegetable crop production are important enterprises.

The Northern Atlantic Slope Diversified Farming Region (S) is relatively small (40,840 mi²) but is very important because of its highly diversified farming operations. This temperate, humid region consists of lowlands, coastal plains, the piedmont, and ridges and valleys. The frost-free period ranges from 120 days in the mountains to 220 days in the Chesapeake Bay area. Udalfs, Udults, and Ochrepts are the dominant soils. Aquults and Aquepts occupy lowlands and depressions on the coastal plains, where truck crops,

fruits, and poultry are especially important. Forage crops, soybeans, and grain crops for livestock are also important. Steep slopes are largely in forests and are used for timber production and recreation.

This publication summarizes research and experience that show the potential benefits and problems related to decreasing tillage and to leaving more residues on the soil surface. In the 14 chapters that follow, experts discuss the equipment, management practices, crop-protecting chemicals, crop rotations, cover crops, and cropping systems that enable farmers to control erosion on their lands—so they are in Federal conservation compliance—and also to optimize their net returns and improve the environment and natural resources.

Other Source

U.S. Department of Agriculture, Agriculture Handbook No. 296. 1981. Land Resource Regions and Major Land Resource Areas of the United States. Soil Conservation Service.

2 Terminology for Crop Residue Management

D.L. Schertz and W.J. Becherer

This publication is one of six regional publications that summarize and interpret data on crop residue management to help in the adoption of this technology. The term *crop residue management* is relatively new, and it is important to understand how the term is used in these publications.

In the early 1960's, the terms *minimum tillage* and *reduced tillage* were used to denote fewer trips over the field. These fewer trips may or may not have left residue on the soil surface after planting or during the critical wind erosion period. These terms did not quantify the surface residue left or the resulting reduction in erosion. The term *conservation tillage* also became popular. This term did imply that some surface residue was left but initially did not specify an amount.

In 1984, the U.S. Soil Conservation Service defined *conservation tillage* as "Any tillage and planting system in which at least 30 percent of the soil surface is covered by plant residue after planting to reduce soil erosion by water, or, where soil erosion by wind is the primary concern, at least 1,000 pounds per acre of flat small grain residue-equivalent are on the surface during the critical erosion period."

This definition remained through the early 1990's. The objective of conservation tillage was to leave surface residue to reduce the eroding forces of rain and wind.

Specific types of conservation tillage are no-tillage (also called no-till), ridge tillage (ridge till), and mulch tillage (mulch till). They are defined by the Conservation Technology Information Center as follows:

No-till: The soil is left undisturbed from harvest to planting except for nutrient injection. Planting or drilling is done in a narrow seedbed or slot made by coulters, row cleaners, disk openers, in-row chisels, or rototillers. Weed control is done primarily with herbicides. Cultivation may be used for emergency weed control.

Ridge-till: The soil is left undisturbed from harvest to planting except for nutrient injection. Planting is done in a seedbed prepared on ridges with sweeps, disk openers, coulters, or row cleaners. Residue is left on the surface between ridges. Weed control is done with herbicides or cultivation or both. Ridges are rebuilt during cultivation.

Mulch-till: The soil is disturbed prior to planting. Tillage tools such as chisels, field cultivators, disks, sweeps, or blades are used. Weed control is done with herbicides or cultivation or both.

These definitions have gained considerable acceptance. However, some confusion remains as to the meaning of conservation tillage. Research shows that surface residue of less than 30 percent may considerably reduce erosion even though, by definition, this amount is not considered conservation tillage.

Most farmers chose to comply with the 1985 Food Security Act to maintain eligibility for USDA program benefits. Many farmers selected conservation tillage practices that left sufficient crop residue on the surface to meet their conservation goals. However, some tillage practices were selected that left less than the amount required to be classified as conservation tillage, but were combined with other practices to achieve their conservation goals. Adding to the confusion, some people referred to conservation tillage as meaning only no-till. It became clear that standard terminology was needed to clarify the impacts of leaving all or a portion of the previous crop's residue on the soil surface. The term *crop residue management* evolved to address the benefits of surface residue in reducing soil erosion.

The practice of crop residue management encompasses an entire cropping year as follows: (1) A crop is planted that will provide residue to meet a specified goal, such as keeping erosion within a specified limit. A cover crop, where applicable, is often used with low-residue crops to achieve additional residue cover. (2) At harvest there is good distribution of residue. This is an essential component. (3) The depth, speed, and tools involved in any tillage operation are carefully planned to maintain the desired amount of residue on the surface.

Crop residue management is defined as follows: Any tillage and planting system that uses no-tillage, ridge tillage, mulch tillage, or another system designed to retain all or a portion of the previous crop's residue on the soil surface. The portion required depends on other conservation practices that are included in the farmer's total conservation plan.

Throughout these six regional publications, the terms *reduced tillage*, *minimum tillage*, *conservation tillage*, and *crop residue management* are used interchangeably. Each term refers to a system that leaves all or a portion of the previous crop's residue on the soil surface to reduce soil erosion to an acceptable level.

3 Description and History of Surface-Residue Tillage Systems

L.D. Hoffman

Residue management is a relatively new term to farmers and agricultural professionals. But the idea of farming in high-residue conditions is not a new idea to many farmers throughout the Appalachian and Northeast region of the United States.

Pioneers of No-Till Farming

In Appalachia and the Northeast, a longstanding and growing interest in no-till farming has persisted. In fact, the idea was hatched, nurtured, and “brought to harvest” in this region. When identifying the early pioneers of no-till farming, we may overlook some important names, but we must not fail to mention Harry Young and Shirley Phillips of Kentucky, Will Moschler of Virginia, Joe Newcomer and Allan Bandel of Maryland, Bill Mitchell and Tom Williams of Delaware, and Willis McClellan of Pennsylvania. Except for Harry Young (a Kentucky farmer often credited as the first farmer of no-till), all named here are university people who offered early leadership in testing, studying, and—most importantly—demonstrating to farmers the usefulness and promise of the concept of no-till farming.

Many farmers were also pioneers of this concept. Each state and many communities had their own Harry Young. No new agricultural concept has been more quickly accepted and adopted on farms throughout Appalachia and the Northeast than has no-till farming. In fact, those early innovative farmers pushed the researchers and extension professionals to keep up. In some states in the region, the Natural Resource Conservation Service (NRCS) was the leading force in the adoption of this practice. Other states saw the Extension Service as the standard-bearer. Farmers in a few states were fortunate because both of these agencies worked together, enabling the farmers to be more quickly and better informed.

Early Motivation for No-Till Farming

Although the primary objective of most agricultural professionals in encouraging the adoption of no-till farming was to reduce soil erosion, most farmers quickly recognized the potential for increasing their net profits. This motivating factor soon became the force behind the acceptance of no-till farming on many farms throughout the region. From the late 1960's through the 1970's throughout the region, a dramatic increase was seen in no-till corn and soybeans and—to a lesser degree—in no-till alfalfa and small grains. The rate of increase of no-till acreage was greater here than in any other U.S. region.

Some of the conditions in Appalachia and the Northeast that made this region more receptive to the adoption of no-till were the smaller farms with smaller fields and also the topography of steep slopes that made erosion control vital. The savings in labor with no-till allowed many farmers to spend more time with their livestock enterprises or to expand their crop acreage, while continuing to grow crops in a timely and profitable fashion.

The many owners of small farms quickly saw the benefits but believed they could not afford the increased cost of no-till planting equipment. Officials in many soil-conservation districts recognized this dilemma and purchased no-till planters and drills and rented them to farmers. This machinery was a great help. A person who has not farmed under stony conditions cannot fully appreciate how much the reduction or elimination of rock picking influenced farmers to buy their first no-till corn planter. Many factors made the concept of no-till right for the region and for the time.

In the late 1960's when the interest in no-till crop production was just beginning, very little minimum till or reduced till farming was being practiced throughout the Appalachian and Northeast region. A few farmers in pockets, here and there, were trying “wheel track planting,” chisel plows, and offset disks, but the moldboard plow was the primary tillage tool on nearly all farms throughout the region.

Early Efforts in Erosion Control

Up to the late 1960's, most farmers were concentrating on using stripcropping, crop rotations, contour farming, diversions, and cropland terraces to keep soil erosion to a manageable level. The positive impact of crop residue on erosion control in no-till fields led to the increased adoption of chisel plows and offset disks on many farms. During the 1970's, many of the acres previously tilled with moldboard plows were tilled with chisels and disks. Farmers found this a great way to reduce fuel costs, speed up the tillage operation, reduce soil erosion, avoid dead furrows, and (in the case of the offset disk) reduce the amount of stone picking on stony fields.

In the early 1960's, moldboard plowing was used on 95 percent of all tilled acres; two decades later, moldboard plowing had been reduced to less than 50 percent of total acres. It is noteworthy that during 1980–85, a major part of the increase in chisel-plow acreage in this region came from land previously in no-till! Some of the common reasons for this change are pressures from shifting weed species (deep-rooted perennials like mulberries, hardwoods, Canada thistle, horseweed, briars, and Virginia creeper); soil compaction; rough and rutted soil surfaces; and urban pressure on some farms to incorporate manure. In these cases, some tillage was viewed as a logical corrective strategy.

Later Motivation for No-Till Farming

Many factors influence farmers to make subtle changes in their tillage techniques. In the mid-Atlantic states, drought is a powerful force in changing the decisions of farmers. Historically, dry weather during the late growing season made the water-conservation benefits of no-tillage especially desirable. Conversely, extreme dry weather early in the growing seasons of 1987, 1988, and 1991 made mulch till and conventional till more profitable for most crops in the region. Modest changes in the acreage devoted to various tillage systems often reflect recent weather patterns.

Other factors that favored the acceptance of no-till were well-drained limestone soils; a high concentration of dairy farms where labor or time allocation for crops was short; highly erodible soils; an effective demonstration program; and most important, a county agent and NRCS organization that were supportive and that challenged farmers to accept the practice. Many states had counties like Franklin County (PA) where the proper mix of the above factors was found, and the adoption rate of no-till was high.

During the 1980's we began to hear the term *conservation tillage*, and its definitive terminology began to be attached to the loosely described terms of minimum till, reduced till, mulch till, and ridge till.

Do We Have the Real Thing?

A funny thing happened during the last 30 years: We farmers and agricultural professionals got sidetracked. We became so enthralled with the equipment and the concept that we forgot about the residue. Many farmers adopted conservation tillage; that is to say, they abandoned the moldboard plow and thought they were conservation-tillage farmers. However, closer looks at their tillage practices revealed that many of those farmers were not then and are still not now meeting the conservation-tillage criterion of leaving 30 percent or more surface residue at planting time.

It has been the move of the 1990's throughout the region to attach the term *residue management* to the well-accepted practices of conservation tillage. The language in the 1985 Farm Bill has certainly increased the importance of the term *residue management*. This Bill raised the interest level of many farmers and made them receptive to the challenge. However, at that time we talked about the tool used rather than the amount of surface residue left on top of the ground after planting. Throughout the 1970's and early 1980's, we spent countless hours and energy teaching the mechanics of the system. When in the late 1980's and early 1990's we finally started measuring the residue present after planting, we found that many of the accepted "conservation tillage systems" that some farmers were using were not leaving sufficient residue to be effective erosion-control techniques.

So it is critical for farmers to be able to recognize the residue levels and to know the impact of various tillage practices on final residue levels. We need to redouble our teaching efforts in this regard. The growing trend in the region to more soybeans, along with the limited amounts and rapid decomposition of soybean residue, makes it imperative to direct the attention of farmers to establishing corn, small grains, and other crops by no-tillage when following soybeans on highly erodible soil.

It is difficult to draw a progression of the adoption of no-till over the past two decades because the numbers are sketchy. Also, changes in survey techniques over this time prevent the comparison of annual averages.

Techniques Used Today

Figure 1 indicates that the Appalachian and Northeast region have stabilized at about 35 percent of all crop acres planted with conservation tillage techniques. No-till continues to account for over half of the conservation tillage acres in the region. Although there is room for continued improvement in the adoption of conservation tillage, one must remember that this region has a higher percentage of stripcropping, higher percentage of contour farming, and a higher hay-to-grain ratio than do most other regions in the United States; and these continue to be powerful erosion-control techniques regardless of the type of tillage.

Description of Various Surface Residue Systems*

The conservation tillage systems used in surface-residue management as outlined and defined by the Conservation Technology Information Center (CTIC) are given in chapter 2. Those systems include no-till, ridge-till, and mulch-till—all defined as retaining 30 percent or more residue on the surface.

To complete the definition of all types of crop residue management, the following two categories include systems that leave less than 30 percent cover:

15–30 Percent Residue Cover: Tillage types that leave either 15–30 percent residue cover after planting, or 500–1,000 lb of small-grain residue equivalent during the critical wind erosion period.

Less Than 15 Percent Residue Cover: Tillage types that leave either less than 15-percent residue cover after planting, or less than 500 lb of small-grain residue equivalent during the critical wind erosion period.

* Taken from Conservation Technology Information Center (1991)

In the following text, the different conservation-tillage systems described in chapter 2 are examined for their strengths and weaknesses:

No-Till

No-till is clearly the most effective system for minimizing erosion. Depending on the type of coulters used on the planter, the resulting disturbance to surface residue is 3–12 percent. No-till is easily the most fuel- and labor-efficient of all the systems. It thus offers operators free time to be used in expanding their crop base or in other facets of their operation such as livestock, dairy, or off-farm interests. The shortcomings of no-till production include the following: An increased level of management is needed; cold and/or poorly drained soils do not respond as well to no-till (but recent row-cleaning devices have significantly reduced this concern); weed shifts often include the encroachment of hard-to-control deep-rooted perennial weeds; the levels of some plant diseases and insects may be increased; and soil compaction can become a yield-limiting factor when heavy equipment (such as manure spreaders, combines, and lime trucks) is operated under less-than-optimum field conditions. But these shortcomings should not disqualify no-till from being considered for any farm. Management techniques are emerging that will correct or avoid these shortcomings, thus allowing more farmers to benefit from the positive effects of no-till.

Ridge Till

The ridge till system has particular merit on some soils that lack optimum drainage. In this system, a ridge is formed during the growing season with one or more operations of a ridge-forming cultivator. This has the following benefits: A raised seedbed is prepared for next year's planting, and it should be dryer and warmer than the seedbed in unridged conditions. Some soil is loosened, but the residue is left undisturbed for those periods when erosion is most likely to occur. Some weed control results from the action of the cultivator tools. And finally, the resulting semicontrolled traffic pattern helps to reduce soil compaction on most of the field. But the popularity of ridge till is lower in the Appalachian and Northeast region than in some areas of the Corn Belt because of the following: Small irregular fields are not as convenient for ridge till farming; steep slopes demand that ridges be placed on the contour to avoid serious erosion problems; subsequent operations such as manure spreading and silage harvesting make it difficult to conserve the integrity of the ridges; and the requirement of one or two row cultivations for weed control and maintenance of ridges tends to limit the total acreage farmed.

Mulch Till

Mulch till is a catchall category that requires some serious training for farmers, if it is to be the viable soil-erosion concept that it can be and deserves to be.

Importance of Secondary Tillage Operations

As indicated earlier, many farmers throughout the Appalachian and Northeast region adopted the chisel plow and offset disks as their primary tillage tool of preference. Unfortunately, they did not limit their secondary tillage operations to ones that conserve the surface residue. On some farms, residue levels were reduced to nearly that following the moldboard plow. In the late 1980's and early 1990's, manufacturers, researchers, and innovative farmers have learned how to better equip both the primary and secondary tillage equipment to enhance the amounts of surface residue left on the field at planting.

Quantifying the Crop Residue

When farmers are able to quantify the degree to which crop residues are covering their soils, their goals can be more easily set and achieved. The line-transect method of counting surface residue requires only minimal investment in equipment and training, and will suffice until automated cover meters are available. With this ability to quantify cover, the farmer is able to equip or operate tillage equipment in such a way that surface-residue levels are maximized while some of the reasons for tillage are still being accomplished. A subsequent chapter deals with how to influence those residue levels.

Most-Cost-Effective Changes

My experience indicates that the most-cost-effective changes a farmer can make are the following: changes in tine configuration (narrow, straight teeth on chisel plows rather than wide twisted ones, and undercutting sweeps on field cultivators rather than straight teeth); reduced depth and speed of travel with any tool, especially with a disk; and fewer trips over the field. The bottom line is that we need a planter or drill that can perform effectively in high-residue conditions. Then we can eliminate many of the tillage operations of the past.

What Is Needed To Make High-Residue Farming Better and More Acceptable?

Experience indicates that the most common reasons for the reluctance of farmers to adopt these practices that keep some residue on the surface are concerns for weed control, insect and disease problems, concerns for productivity, lack

of availability of equipment, a belief that “it won’t work on my farm,” and conflicting information.

Control of Weeds

Under no-till management, the numbers of annual weeds generally decline but perennial weeds are more persistent. These changes often result in the presence of weed species that most farmers have not dealt with during conventional tillage. These shifts in weed populations cause many farmers to be unfamiliar with their early identification, effective herbicides, and the necessary timing of herbicide techniques. Deep-rooted perennial weeds are tough to kill, but they don’t develop to problem numbers overnight. Therein lies the key. In these high-residue farming programs, the farmer needs to control deep-rooted perennial weeds when they first occur, not after they become a catastrophe. The rotation of crops will help significantly by allowing the use of different herbicides and different rates. That is, it is often possible to apply more appropriate herbicides at higher rates between crops than if one continuous crop, such as corn, is present. Generally the cost of weed control can be kept down if the control follows the principle of Get them when they are little, because big, tough weeds are hard to kill!

Control of Insects and Diseases

Fortunately, insect and disease problems (from leaving residue on the surface) have never materialized to the degree that most professionals predicted two decades ago. This is not to suggest that residue burial was not and will not continue to be an effective tool in the control of disease and insects. It does suggest that high-residue farmers must recognize the potential for increased pressures and then manage accordingly. In much of the Appalachian and Northeast region, occasional pressures from black cutworm and armyworm, for example, dictate that farmers must regularly inspect their corn fields from the time of emergence to the six-leaf stage, or else apply a preemergence insecticide. Clearly the more-cost-effective option is to inspect or “walk” the fields and use insecticides only when insect populations are so high that the cost of their control is less than the value of yield reduction that they would cause.

Although isolated pressures of gray leaf spot are occasionally attributed to surface residues in this region and can be serious and expensive when environmental conditions are right, few documented cases exist of other diseases occurring at an economically important level as a result of residues left on the surface. However, one should select the cultivars with the highest level of disease resistance available for diseases that can become troublesome in the area. Observations—especially in the mid-Atlantic area of the region—lead to the conclusion that there is little difference in disease occurrence between no-till and mulch till situa-

tions even when the mulch till has less than 30 percent residue. Again, the key to success is to be prepared!

What To Do About Problem Soils

Productivity on light, sandy soils for most crops is usually enhanced when tillage is reduced or eliminated and residue levels are high. On heavy, poorly drained soils, the opposite can be true. Again, with a change in management techniques to use crop rotation, to achieve better timing of field operations, and to use crop varieties with good seedling vigor and early emergence, the problems of no-till can be minimized or eliminated on most farms. Even in conventional tillage, farmers have learned to farm some soils differently from others. If certain soils are less conducive to high-residue farming, the farmer must learn some micromanagement under high-residue levels. The *easy* management technique under these conditions is to get out the plow. That may not be the most economical approach, and it is not the most environmentally friendly. On some farms where erosion is a problem, the plow may not even be an option in the future. We must learn to make high-surface-residue farming highly productive and profitable even under less-than-ideal conditions. Row cleaners and zone tillage may be useful in such circumstances. Fortunately, farmers and their advisors are rapidly solving these problems.

Modern Agricultural Equipment

The agricultural equipment industry has met the challenge of high-residue farming. Excellent planting equipment has been developed to plant nearly all crops in high levels of residue. And industry continues to refine this planting equipment. In the past several years, an influx of new tillage equipment makes it possible to accomplish the necessary tillage when and where needed and yet leave acceptable levels of crop residue on the soil surface. That equipment is now in the marketplace. When farmers are replacing their present tillage equipment, these high-residue tools should be on their shopping lists.

Rising to the Challenge

“It works for my neighbors, but I don’t think it will work on my farm.” This statement is often heard at field days and winter meetings, and it may be true. To benefit from savings of oil, soil, and toil from high-residue farming, one must be willing to invest in the dedication to management, timeliness, and change that is necessary to make high-residue farming profitable. Most farmers in the Appalachian and Northeast region have eagerly risen to that challenge, but some may never do so!

There is a real problem of conflicting information coming to the farm gate from various agricultural agencies and commercial firms. Fortunately, these instances are fewer

and fewer each year. One can argue that pressures from the 1985 Farm Bill and Government programs are responsible for this change. More importantly, it is likely that a growing awareness of the positive influence of high-residue agriculture has more people working toward this common goal. A positive step is the creation of organizations like the National Crop Residue Management Alliances, where state and Federal agencies and agribusiness join together to develop a common agenda to make crop residue management work. State and county workshops for all agricultural advisors—including extension, NRCS, ASCS (Agricultural Stabilization and Conservation Service), Farm and Home Administration, farm machinery and equipment dealers, and

crop-supply dealerships—are needed to further reduce the instances of conflicting information.

Farmers and agricultural professionals alike go into the 21st century with dedication to the following principle: We don't inherit the land from our ancestors, we borrow it from our grandchildren. From this dedication, high-residue agriculture will continue to grow.

Reference

Conservation Technology Information Center. 1991. 1991 National crop residue management survey. West Lafayette, IN.

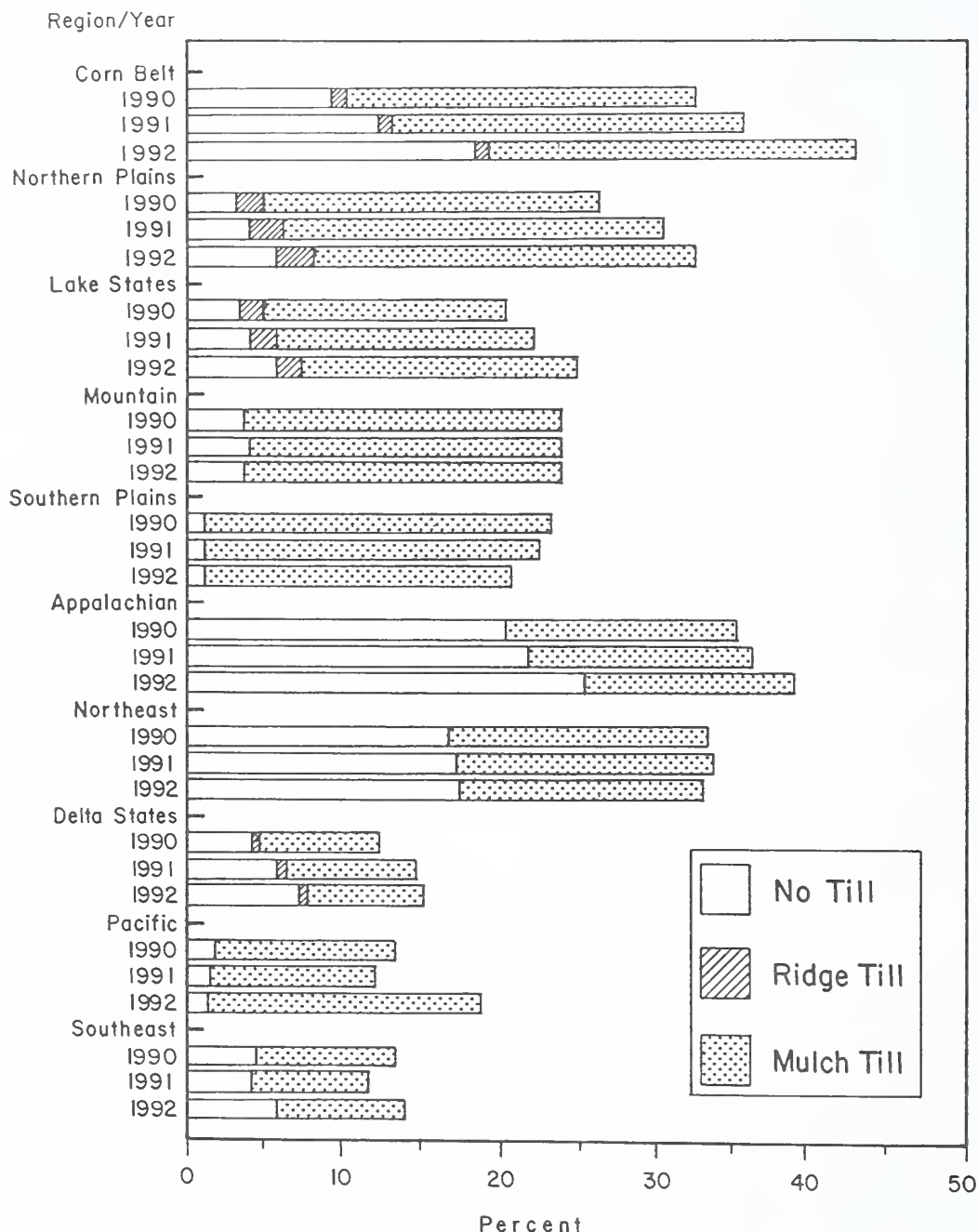


Figure 1. Percent acres planted with conservation tillage, by region and tillage practice (1990–92)

4 Interaction of Surface Residue With Soil and Climate

J. Mt. Pleasant and F.B. Gaffney

Surface crop residues affect and are affected by the cropping system, which in turn is largely controlled by the environment. Although the crop selection and the many management decisions that accompany each crop are often the result of soil and climatic restrictions, these same decisions determine the occurrence, type, and quantity of surface residue.

On a given farm, the decisions concerning the number of years in row crops compared to the years in small grains or hay are based on many factors. In the Northeast and Appalachia, much of the cropland is in forages to support dairy animals and other livestock that require a variety of feeds to achieve balanced nutrition. These farmers develop cropping systems to meet the complex needs of a livestock-based agriculture, as restricted by the soil and climate of their particular fields.

The quantity of surface residue will change dramatically with the cropping system. For example, residue under continuous corn differs greatly from residue under a cropping system of 1 yr corn and 4 yr alfalfa. Fields in continuous corn require deliberate efforts to manage crop residues in order to protect the soil. In contrast, fields in hay or small-grain production have substantial plant cover year-round and need few if any efforts to provide additional protection.

In continuous-corn systems, the amount of surface residue varies enormously, depending on whether it is harvested as grain or silage. Generally, fields in continuous silage production are among the most vulnerable to erosion because they are left almost bare after crop harvest, with only 10–20 percent ground cover. Further loss of ground cover will occur over the winter months. Fall and winter precipitation can cause severe erosion on unprotected fields. To increase the surface residue, substantial changes will need to be made in the management of these fields.

Conversely, continuous corn grain production can leave substantial residue on the soil surface: as much as 90 percent ground cover. To reduce the erosion on these fields, modest changes in tillage practices may be all that is required. However, if the corn stover is baled, the ground cover is drastically reduced to less than 30 percent.

Erosion-control practices are critical components of any farming enterprise. The percent soil cover may be reduced if residue management is complemented by other practices. Diversion ditches or terraces intercept water flowing over the soil and then channel the water across the slope to safe

outlets. When a diversion is included in the erosion-control scheme, sometimes the amount of crop residue needed to control erosion can be reduced. This decision must be discussed with the county's Natural Resource Conservation Service to ascertain if the alternative meets the needed level of erosion control.

Crop rotations aid in controlling diseases and insects if the rotation includes a change in plant family. A common rotation is corn followed with alfalfa. This particular rotation has the added benefit of improving the soil organic matter and soil tilth. The soil-tilth benefit is reflected in higher corn yields following the alfalfa. This benefit is greatest during the first year of corn but then decreases over the next 1–2 yr. After 3 yr, the soil-tilth benefit is little or none.

Managing large quantities of crop residues in the northern or high-elevation areas of the Northeast and Appalachian region may differ from managing those in the more southern areas because of the effects of cooling and of moisture retention. The primary concern about many northern soils is the drainage of surface water and subsurface water. Where drainage is not adequate, shaping and smoothing of the soil surface will prevent the ponding of water on the field, and this will allow quicker warming of the soil. Subsurface drainage offers many opportunities for improved management. This internal soil drainage allows the soil to warm up sooner in the spring and also allows on-schedule field operations that usually do not result in tire ruts and other severe compaction.

Well-drained soils are drier, warm up more rapidly, and are easier to manage than poorly or somewhat-poorly drained soils. Consequently, higher water contents and lower temperatures commonly associated with residues on the soil surface do not significantly delay planting and seedling emergence, and residue on the surface is generally beneficial. On well-drained soil, practices associated with the production of crops are relatively the same for methods that leave residues on the surface and for conventional methods, except for tillage operations.

High-Residue Systems Versus Low-Residue Systems

The management practices and the interplay between residue, cropping system, and environment are distinctly different for high-residue systems and low-residue systems. For this discussion, the cropping systems are distinguished according to the level of surface residue. In high-residue conditions, changes in tillage practices alone may be sufficient to protect the soil. In low-residue conditions, more substantial modifications are likely needed.

Under high-residue conditions, changes in the timing and type of tillage can be used to better manage the existing crop residues. Residues must be left intact over the winter to effectively protect the soil. Delaying the tillage until spring or reducing the tillage (or both) will help provide adequate cover. The primary concern in these systems is the rate of residue decomposition, which is determined by air temperature, moisture, initial nitrogen content, and residue placement (see ch. 10). Thus, where winter conditions are colder and the amount of snow cover is greater, less biomass is decomposed. The residue decomposition rate is therefore important when computing how much residue must be left on the surface in the fall to achieve the percent ground cover at planting time that is specified in the conservation plan, especially in the southern portions of the Appalachian and Northeast region where decomposition rates can be high. In northern portions of the region, farmers need to bear in mind the cooler spring soil temperatures that result from the mulch effect of the residue. Management options like ridge tillage, shorter-season varieties, and timely planting may be needed, to achieve early emergence and adequate growth of corn plants.

Use of Cover Crops in Low-Residue Systems

Cropping systems that leave little surface residue require substantial changes in management practices to provide sufficient protection for the soil. Fields in silage corn and row-crop vegetables are common examples of these low-residue systems in this region. The introduction of cover crops is the best way to increase the surface residue in systems that have inherently low amounts of residue. (Additional aspects of cover-crop use are discussed in ch. 13.)

Fall Establishment

When most of the crop is removed at harvest, as is done with corn silage, it is essential to seed a fall cover crop to protect the soil over the winter. But successful establishment of this fall cover crop largely depends on the length of the growing season after harvest. In much of the upper northeast (New York and New England), winter rye is about the only crop that can be reliably established in fall. Legumes cannot be successfully established after August 20 in the more northern areas of the Appalachian and Northeast region, and even forage grasses such as ryegrass and fescue do poorly when seeded in fall.

The concept of growing degree days (GDD) is useful in interpolating responses from other years and locations to make decisions on a specific farm. For rye, the number of GDD credited to a day is the average temperature in degrees (Fahrenheit) minus 40 °F. For instance, if the normal average temperature expected on a given day is 50 °F, it is

likely to provide 10 GDD. A more complete discussion of GDD is provided in chapter 13.

Rye requires about 350 GDD for successful establishment and to accumulate sufficient biomass to overwinter. The number of GDD available after September 30 in the Northeast and Appalachian region ranges from 286 to 952 (see table 9 in ch. 13). Consequently, the cutoff date for seeding rye in this region ranges from mid-September to mid-November.

In much of the upper region, the use of cover crops is limited due to the lack of GDD if silage is harvested late or if corn is taken as grain. However, cover crops can be seeded earlier into standing corn during cultivation or sidedressing operations, greatly increasing the selection of species that can be used. Successful establishment with an earlier seeding depends primarily on adequate rainfall for germination.

In the upper Northeast and Appalachian region, the short time between seeding dates and the onset of below-freezing temperatures also greatly restricts the dry-matter accumulation from cover crops in fall. In New York and New England, fall-seeded cover crops are unlikely to attain more than 500–800 lbs/acre dry matter before winter.

Producers farther south (southern Pennsylvania, Maryland, Delaware, Kentucky, and West Virginia) have a longer growing season and thus have more options in the selection of species and seeding date. Many species, including legumes, can be successfully seeded in fall in this area. The cutoff date for crops like winter rye is also much later, which allows greater flexibility. In Maryland, West Virginia, and Kentucky, the longer growing season permits the seeding of rye even in November. The longer growing period in the fall season in these states also allows cover crops to accumulate substantial biomass—as much as 2,000 lb/acre dry matter—before low temperatures halt the growth.

Spring Management

Climate also affects the management of cover crops in spring. The accumulation of biomass by cover crops increases dramatically in spring. In New York, winter rye frequently doubles in biomass between May 1 and May 20. Researchers in addition to the authors of this chapter have noted that winter legume cover crops make most of their vegetative growth in the 3-wk period immediately prior to entering their reproductive stage. In most of the Northeast and Appalachian region, this period of very rapid growth occurs between April 1 and May 30, depending on the latitude and elevation.

A later kill date allows maximum accumulation of biomass; in the case of legume cover crops, this greatly increases their nitrogen contribution to the cropping system. Increased biomass also means greater additions of organic matter to the soil, which enhances the physical environment for crop growth. Under no-till, greater biomass provides a more effective mulch for suppressing weeds.

However, there can be negative effects from large amounts of cover-crop biomass: (1) Late-killed cover crops can be difficult to incorporate, which can hinder the tillage, planting, and weed-control operations, or can require the use of planting equipment and weed-control equipment adapted to surface residues. (2) The decomposition of large amounts of grassy residues can tie up nitrogen in microorganisms and thus decrease the nitrogen available to the crop; so spring-planted crops may require increased fertilizer nitrogen. (3) Actively growing cover crops deplete soil moisture, which can increase water stress and reduce yields. However, in poorly drained situations, this depletion of soil moisture can bring soils to a more favorable water content and thus increase the yields. The difference is often a matter of killing the cover crop at the right time. And determining the right time requires close surveillance and experience. (4) Large amounts of grassy residues may inhibit germination in some spring-planted crops.

Surface residues greatly affect pest management. Heavy residues may decrease the effectiveness of soil-applied herbicides by intercepting a significant portion of the material, and may increase the dependence on postemergence herbicides. Residues can also plug tine weeders and row-crop cultivators used to control weeds. Surface residues also impact the populations of insects, disease, and nematodes. (These problems and their solutions are discussed in more detail in ch. 12.)

Surface residues can lower soil temperatures, which reduces germination and slows the emergence, growth, and development of crops. These effects are magnified on wet soils.

Difficult Situations

The northeastern states are characteristically cold and wet in spring during the normal corn-planting period. As a result, any surface residue that provides a mulch on the surface will delay soil warming. Temperature is only one environmental factor; it is interrelated with soil moisture, soil gases (CO₂ and O₂), and mineral concentration. Soil temperatures down to 3 ft or more are affected by the type of ground cover or tillage practice or both. The relative lack of success of no-till techniques in the extreme Northeastern United States may be caused by the reduced warming of wet soils due to the interception of solar radiation by surface litter. Some evidence exists of measurable effects on crop growth by temperature differences as small as 2 °F, especially at

temperatures around 60 °F in the root-tip zone. In this cold region, soil temperature needs to be a primary consideration but should not exclude other factors that are also economically important. Cultivation or minimum tillage before planting may help reduce the negative effect of cool soil temperatures. The use of row cleaners or zone tillage to move residue off the row where seeds will be planted will also help.

The selection of appropriate cultivars may be important. Root growth and plant-top growth vary considerably among crop varieties. To obtain the best variety for any area, consult the local Cooperative Extension Service.

In the development of a cropping system, there are several decision points at which changes can increase the residues. Changing from low- to high-residue cropping systems may require changes in tillage and planting equipment, pest management, fertilization, and choice of hybrid. Cover crops of many different species are available. In the northern states, rye (*Secale cereale*) is the most reliable when growing seasons are short. Winter wheat (*Triticum aestivum*) is common but must be planted earlier in the fall than rye. These may be grown for winter cover, but spring management will determine the amount of residue that will remain. Two harvest techniques—removal of leafy vegetative material and harvest for seed—may result in significantly different amounts of residue. Some dairy farmers will allow the rye or wheat to grow in spring and then either green chop or graze the field to a 3- or 4-inch stubble. This stubble will generally provide adequate protection from raindrop impact on erodible fields planted without tillage to corn. In situations where the grain is harvested, frequently the grass or legume or legume-grass mix is broadcast seeded or no-till drilled in spring, thus allowing the hay crop to become established before grain harvest in June or July.

The most common row crop in the northern states is corn, frequently in rotation with a hay crop. On highly erodible land, permanent hay is best, because it provides surface cover year-round. Some producers have no use for hay, so they require other systems to control erosion.

Set-aside and conservation-use acres are programs of the Agricultural Stabilization and Conservation Service (ASCS). These programs offer unique opportunities for managing surface cover and reducing erosion. Although these are annual practices, either annual or perennial cover may be planted in these fields.

Growers should systematically evaluate their options in their cropping systems. Before initiating large-scale changes in residue management, it is prudent to first develop management skills on a smaller scale.

5 Effects of Tillage and Residue Management on Water for Crops

W.M. Edwards

Precipitation

For the most part, farmers in the Appalachian and Northeast region of the United States rely on rainfall in early spring and summer to meet a crop's water needs. That means we take it as Mother Nature gives it to us.

The timing of rainfall is important in two ways. First, rainfall is needed to provide the right amount of soil moisture during the time that will enable good yields. Second, the intensity of rainfall within storms that deliver the water is a major factor in determining infiltration, runoff, and erosion. We farmers cannot influence either time variable: when we get the rain or how fast it falls in the storm. However, with the current technology, we have options for managing the schedule of nature's water supply to our advantage.

Today's management practices have evolved over many years of farming. The practices have been influenced by the normal and the extreme rainfall patterns that prevail in different parts of the Appalachian and Northeast region. Years of research and experience have shown that the way we till (or do not till) slopes in this region can affect both the amount of rainwater that infiltrates into the soil and the availability of water to crops throughout the growing season. These two factors are related, because if the rainwater runs off, it cannot be used later.

Infiltration

Effects of Weather and Soils

In the Appalachian and Northeast region, most of the rain that falls on cropland will infiltrate. The rain carries the fertilizers, herbicides, and insecticides into the soil, where they can be used to feed the growing crops and to control weed and insect pests. Rain that does not infiltrate will run off the field and thus remove water, topsoil, and chemicals, which then become unavailable to the production processes.

Several factors influence the distribution of rainfall into runoff and infiltration. Some of these factors vary widely in the Appalachian and Northeast region, and that variation produces different responses to a given management practice in different parts of the region at different times.

For instance, rainfall intensity and the amounts of water in the average storm vary widely across this region (fig. 2). Farmers in parts of northern Alabama, Kentucky, and Virginia can expect to receive over 2 inches of rain in a 30-min summer storm as often as farmers in Maine receive 1 inch. These differences are due to factors like local geography, nearness to the sea, mountains, and continental winds, which are well documented by long-term weather records. If soil and management factors are the same in any two areas of the region, infiltration will be less where rain falls at higher intensities.

Precipitation patterns in winter are usually quite different from those in summer in this part of the United States. Rains in November through March are often all-day drizzles, and the storms are widespread, covering large areas with a relatively uniform amount of water. Raindrops in winter storms are usually small and fall slowly with low impact. Snowfall has little impact energy to affect the soil surface and becomes liquid during gradual melting. In contrast, summer storms usually cover only small areas, produce widely varying amounts of water locally, and contain large drops that fall with high impact energy for just a few minutes.

Many other factors vary from the southwestern to the northeastern areas of the Appalachian and Northeast region. Because Kentucky is much warmer than Maine, the Kentucky soils are more strongly weathered. Intensive tillage in the warmer climate tends to burn up the organic matter quicker than in cooler conditions, so soil aggregates at the surface are more easily broken down in the southern part of the region. As a result, the more intense storms in the warmer areas beat the soil and cause dense, infiltration-limiting crusts on the surfaces of fields that are not protected by mulch or growing vegetation. In the cooler northeastern parts of the region, the higher organic matter of the topsoils helps to bind aggregates together and resist crust formation. Therefore, storms falling on tilled fields in western Kentucky and eastern Maine would produce different amounts of infiltration and runoff on similar slopes.

Subsoil drainage is another important variable. In well-drained soils, if infiltrating rain can get through the soil surface, the rain may move to unsaturated pores located near the surface and be temporarily stored. However, if the soil is poorly drained or has a flow-restricting horizon close to the surface, the upper part of the profile may be saturated, or nearly so, at start of a storm. Under these conditions, poor subsurface drainage can limit infiltration, even though the surface may be well-protected with residue and not crusted. The full benefits of residue management cannot be realized on soils with poor drainage until the drainage problem is corrected. This is an important consideration throughout most of the region.

Effects of Residue Management

For many years, studies using natural and simulated rainfall on small plots and field-sized watersheds have shown that surface residues greatly reduce soil erosion. The same studies also showed that clean-tilled soil surfaces produce more runoff than do soil surfaces covered with vegetation or crop residues. When residue is left on the soil surface as a mulch, the falling raindrops hit residue instead of soil. As a result, the surface aggregates beneath the mulch are not broken apart and dispersed, and the soil surface does not become crusted. Also, the mulch slows down any water flowing on the surface, allowing more time for infiltration.

The widespread acceptance of these relationships led to the definition of “conservation tillage” practices as those that leave at least 30 percent of the soil surface covered with residue at planting time. The benefits of residue management have encouraged the development of tillage practices that preserve the *current year’s* crop residue to increase infiltration in the *following year*.

Watershed-runoff data from two continuous corn watersheds at Coshocton, OH (table 1), show the effects of no-tillage on infiltration. A plowed watershed produced nearly 28 inches more runoff in a 4-yr period than did the nearby no-tilled watershed. No-till management left residues on the surface and reduced the runoff by an average 7 inches each year, putting 7 more inches of water into the no-till soil profile each year. Part of that was used by crops and the rest percolated down, recharging the aquifer; from there it fed nearby wells or flowed from springs as part of the base streamflows.

Many residue-management systems have been tested, and the degree of effectiveness of each has been documented under controlled research conditions. However, many of the factors that influence infiltration have been found to vary widely from place to place and with time. Also, weather inputs for the next year, or the next 10 years, can be only roughly forecast. Therefore, the selection of the best residue-management practice and the prediction of the amount of good that it will do in a given year are somewhat uncertain.

If there were no runoff, there would be no overland (surface) transport of *sediments* or *chemicals* to downstream waters. If it were true that the only effect of residue left on the surface is the reduction of runoff, then it would be a case of the more surface residue, the better. But in some fields, the soils stay wet and cold for too long in spring. And leaving all the residue on their surface would aggravate this problem; it would delay planting, germination, and crop growth and sometimes decrease the yields. In the warmer parts of the region and where the soils are better drained, leaving residues on the surface and keeping the soil cooler

and wetter will usually increase the yields. Because these better drained soils are usually sloping, it may be necessary to cover a substantial portion of their surface with crop residue, to meet compliance with provisions of the 1985 and 1990 Farm Bills.

The residue-management decision must therefore consider a balance between the possible yield-reducing effects during a cold, wet spring and the potential yield-increasing effects during a hot, dry summer. In the northeastern part of the region, it may be that only the shallow or well-drained soils that tend to warm most quickly in spring and that tend to be droughty during normal growing seasons will be good candidates for practices that leave all of the residue on the surface. On those soils the benefits of extra water availability to crops when needed in summer may outweigh any negative springtime effects on moisture and temperature.

In the southwestern part of the region, where crop water needs are higher and where depleted root-zone water supplies in July or August often depress crop yields, most soils will benefit appreciably from management practices that leave crop residue on the surface. Again, the response to a given residue-management practice will be different in different parts of the region and in different weather years.

Evaporation

One of the primary benefits of residue management is its effect on water. By leaving more residue on the surface, we increase infiltration and decrease runoff. That puts more water into the root zone. But the effect of residue on water does not stop there; residue continues to influence what happens to the water that has entered the soil.

During the growing season, water that enters the root zone can leave by three different processes: evaporation, drainage, and transpiration. From the standpoint of crop production, the first two of these processes are losses of soil water. Evaporation transfers water from the soil surface into the air. Drainage takes water out of the bottom of the root zone. In neither of those processes does the water go through the plant. In contrast, in the process of transpiration, water in the soil is pulled into the plant through the roots and emitted as water vapor from the leaves. Some nutrients used by the plant for growth and production also come in through the roots during this process.

Residue acts as an insulator on the soil surface. Energy from the sun dries and warms the residue, but the soil beneath the residue stays much cooler. In Ohio, late-June midday surface temperatures under corn residue are often 10 degrees (F) cooler than those on adjacent bare surfaces. This difference can be even greater in the warmer part of the region. Less evaporation takes place from a cooler, residue-covered soil surface.

In some cases, the extra roughness of residue on the soil surface keeps wind away from the soil. This too may help the residue-covered surface retain more soil water.

How important is evaporation? At Coshocton, OH (which climate-wise is somewhat central in the Northeast-Appalachian region), large weighing lysimeters showed that evaporation from a no-till surface (with residue) was 3 inches of water less than the evaporation with conventional tillage, during the average summer. During those years, average no-till corn yields at Coshocton were 10 percent (11 bushels/acre) greater than those from clean-tilled fields. The increased yields were attributed to the increased infiltration and the decreased evaporation associated with the residue-covered, nontilled fields.

In summers when rainfall is plentiful and can fill the transpirational needs, most of the water saved by decreasing the evaporation goes on down to recharge the aquifer. The timing of rainfall with relation to water requirements of the growing crop varies from year to year, causing these differences. Generally, the southwestern parts of the region lose more water by evaporation from bare surfaces than do fields in the cooler, northeastern parts.

Drainage Losses

Soil has the capacity to hold water, like a sponge, until the crop needs it. This capacity is a function of the amounts and sizes of sand, silt, and clay in the soil and of the organic matter. Recent analyses by Hudson (1994) of the water-holding capacity of soils having about the same amounts of sand, silt, and clay show that for each percent increase in organic matter, the water-holding capacity of soil increases by 3.7 percent of the soil volume (fig. 3). Thus, when the average organic-matter content of the top 6 inches of soil increased by 1.26 percent (fig. 4) during about 20 yr of no-till compared to that of a tilled soil (Edwards et al. 1988), the available water-holding capacity of that top 6 inches of soil increased by about 4.7 percent. This enabled the no-till topsoil to hold about 0.28 inches more water before allowing it to drain.

Organic-matter contents in the lower portions of the soil profile are low, and they did not change in a study by Edwards et al. (1988) as a result of different tillage practices. However, if the crop root zone is filled to the point that drainage takes place four times before and during the growing season, this added water-holding capacity would increase the water available to the crop by about 1.1 inches per growing season. This effect on the available water-holding capacity is just one of several benefits that accompany long-term increases in organic matter after crop residue is returned to the surface and tillage is avoided.

Water-Use Efficiency

Water-use efficiency is a measure of how effectively the water supplies are converted into crop production. It is usually an important concept in areas where the balance between the water input processes (rainfall and irrigation) and the water output processes (runoff, evaporation, drainage below the root zone, and transpiration) result in less-than-satisfactory crop yields.

If rainfall were to always come when needed to supply the crop with adequate water, then water-use efficiency would not be an economic issue. But if our management of sloping fields creates yield-limiting water shortages that are greater than would occur under other management practices, then it becomes clear that we must address the influence of tillage systems and residue management on the water availability to growing crops.

In the drier northern Plains of the United States, winter snow trapped in standing wheat stubble can provide water for use in the following year, and this water makes the difference between having a crop and not having a crop. In the Northeast and Appalachian region, water trapped in snow is rarely an important source of soil moisture for the following season. In much of the region, the average temperature and rainfall distributions are such that it seldom pays to provide irrigation for field crop production. However, good crop residue management and the associated effects on infiltration, water-holding capacity, and evaporation can make substantial differences in yields, especially in droughty soils and in dry years. Under these conditions, keeping residue on the soil surface may increase the water-use efficiency—even in relatively cool, moist climates—by making more of the growing-season rainfall available to the growing crop.

In summary, harvesting is one of the most informative operations in the crop year. It is only when we take the crop out of the field that we get the “bottom line” evaluation of all our management efforts. However, from the standpoints of economics and long-range stewardship, the first trip to the field after harvest may be even more important. How we manage this year’s crop residues that are left in the field after harvest will have a strong effect on next year’s infiltration, runoff, erosion, evaporation, transpiration, drainage, water-use efficiency, yield, and profit.

From the standpoint of crop production and its influence on the crop environment, when we leave residue on the surface, we make the soil cooler and wetter. But if the soil tends to be too cool or too wet, then leaving more residue on the surface can decrease crop production. If the soil tends to be too hot and dry, then more surface residue will help. In the warmer, drier parts of the region, most soils benefit from

extra surface residue; in the cooler, wetter climates, fewer soils may benefit.

When we manage residues properly, we are also managing water. Leaving more residues on the soil surface increases the infiltration and reduces the evaporation and runoff. In some soils and climates, the beneficial effects of increased soil-water availability in droughty periods outweigh the detrimental effects of extra water when not needed; in such a case, the water-use efficiency (as measured by crop produced with the water consumed) can be significantly greater.

Many factors alter the effects of residue-management practices on soil water. These factors vary from place to place within some fields, vary from field to field, and vary from one year to the next. This variation is a major reason for "What worked for one man last year may not work for his neighbor this year." However, a general understanding of these relationships should help guide land-management decisions, especially those that involve tillage and soil water.

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Table 1. Rainfall and runoff from plowed and no-till corn watersheds at Coshocton, OH, 1979–82

Year	Rainfall (inch)	Runoff (inch)	
		Under plowed	Under no-till
1979	44.2	5.5	0.15
1980	46.3	12.3	0.19
1981	41.6	5.6	0.00
1982	35.0	4.5	0.00
Totals	167.1	27.9	0.34



Figure 2. Rainfall amounts (inch) expected to fall in the Appalachian and Northeast region in 30 min with a 25-yr return period. Source: Herschfield 1961.

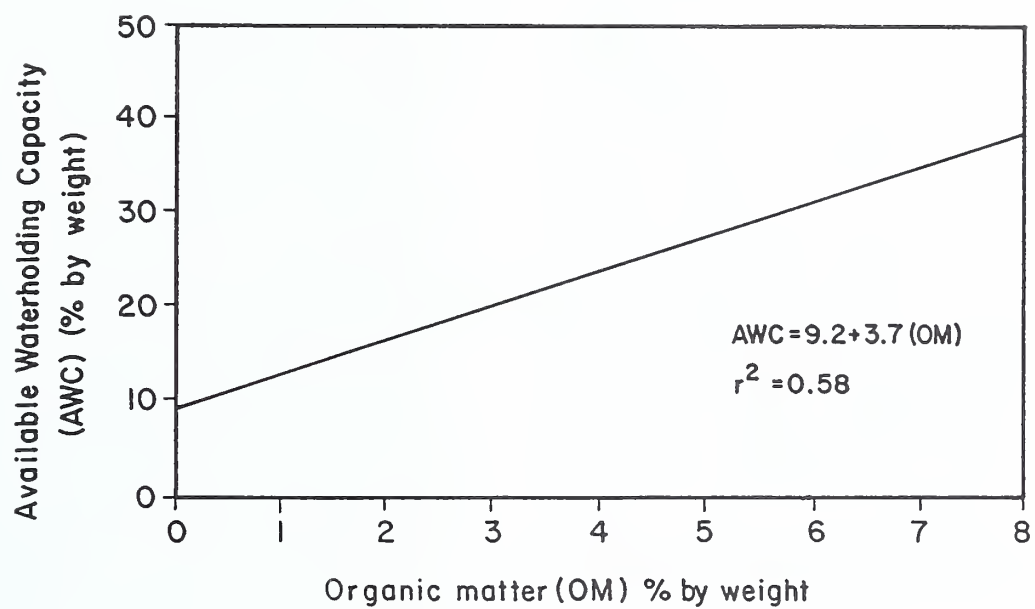


Figure 3. Effect of organic matter (OM) on available water-holding capacity (AWC) of silt-loam surface horizons. Source: Hudson 1994.

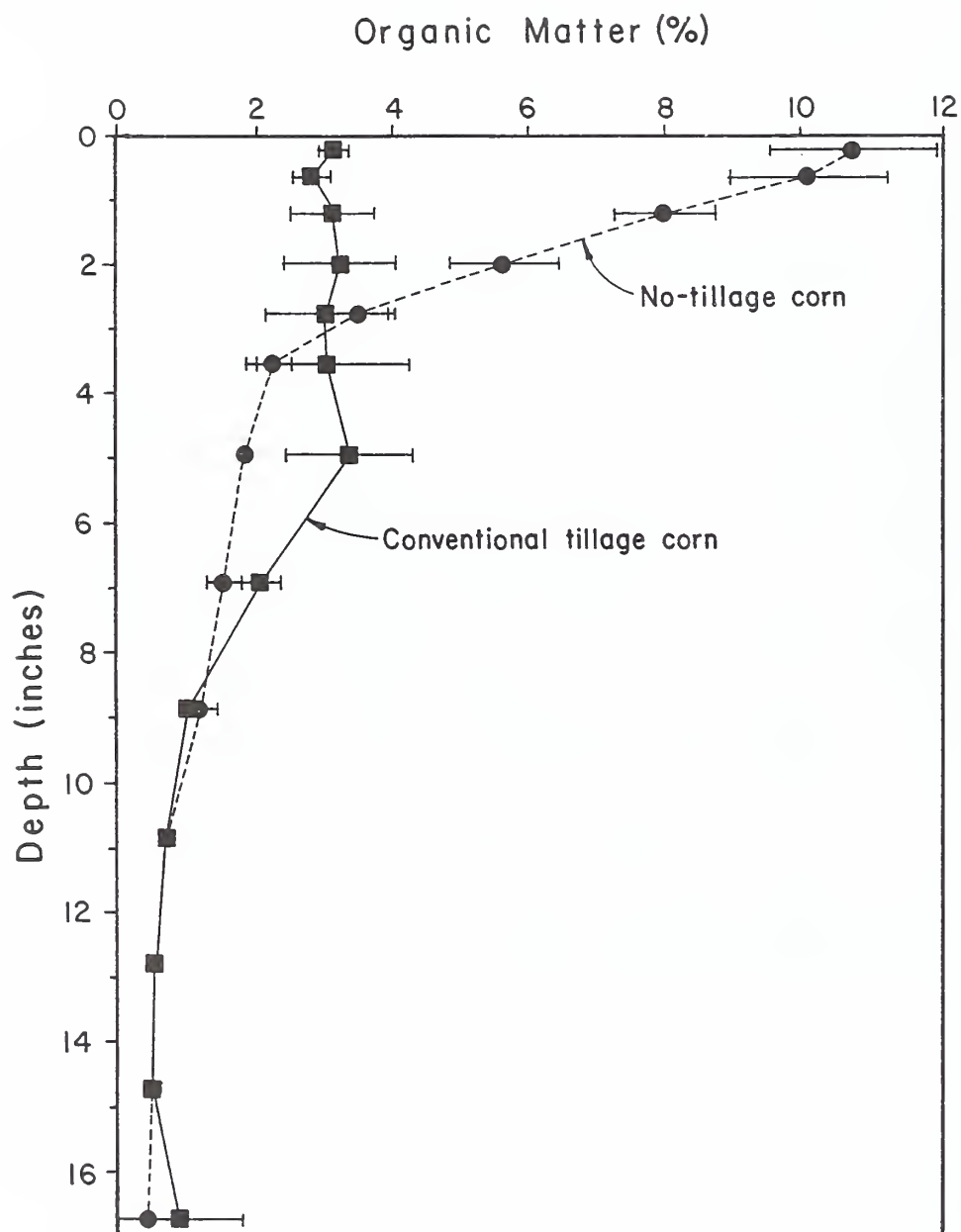


Figure 4. Organic matter distribution with depth in no-till and conventional till silt-loam surface horizons. Source: Edwards et al. 1988.

6 Economics of Residue Management

Jerome Reece

Under the 1985 Food Security Act and the 1990 Food, Agriculture, Conservation and Trade Act, producers who have highly erodible lands will lose eligibility for USDA program benefits if they do not implement all scheduled practices on their conservation plans by December 31, 1994. This in effect puts a value on soil erosion, depending on the worth of the USDA benefits used by the producer. Besides the costs to the producer of noncompliance, there is another issue of the onsite and offsite economic impact of soil erosion and runoff.

Emphasis is being placed on crop residue management because research has shown that improved crop residue management is generally the most cost-effective means for controlling erosion and that 75 percent of the acres under conservation compliance plans nationwide have some form of residue management in them. In Appalachia and the Northeast, the Natural Resource Conservation Service (NRCS) continues its promotion of residue management to aid producers in meeting compliance goals.

Crop residue management is the term chosen by NRCS to replace the term *conservation tillage*. It is a year-round system that begins with the selection of crops that produce targeted quantities of residue and may include a limited harvest of residue. It includes the use of a cover crop if sufficient quantities of residue are not left in the field by the cash crop. Crop residue management includes all field operations that affect the amounts, orientation, and distribution of residue throughout the period needing protection. The terms are not synonymous, although they both refer to the concept of leaving crop residue on the surface to protect the soil from the erosive forces of water and wind. Crop residue management includes conservation tillage as well as other systems that leave less residue.

Crop-Residue Management Systems

The varied topography and climate of the Northeast and Appalachia have led to a variety of crop-residue management systems. Hoffman (personal communication 1991) has stated the following: In the Northeast, the high percentage of corn grown for silage makes it necessary that we develop late summer or early fall seeding of plant material that will achieve adequate fall growth to provide soil protection in spring. Dairy farmers often plant rye, which they subsequently harvest for rye-silage in mid-April to mid-May, depending on the climate. Jane Mt. Pleasant in New York and others (Scott et al. 1987, Janke et al. 1991) have made several studies on evaluating species for seeding at lay-by. These studies indicated that existing herbicide patterns must often be changed to permit late summer seedings that

provide soil protection. Aerial seedings of rye or rye plus hairy vetch into standing soybeans, just before leaf drop, frequently provide extra mulch following soybeans. Often, soybean residue on many farms in the Northeast and Appalachia will not provide 35 percent ground cover, even in well-managed systems.

Many other crops in the Northeast have failed to produce a minimum of 30 percent ground cover after tillage. Preliminary data from a study conducted at Pennsylvania State University's Rock Springs research farm in 1990–91 indicate that only no-till provided more than the needed 30 percent residue cover after planting.

The four basic systems practiced in the Northeast and Appalachia are no-tillage, mulch tillage, ridge tillage, and seasonal tillage. No-tillage is a system of planting crops in a slot in either undisturbed soil covered by crop residue or in a standing crop. In mulch tillage, one manages the amount, orientation, and distribution of crop residue on the soil surface year-round, using a sequence of full-width tillage and planting operations. In ridge tillage, one manages the amount, orientation, and distribution of crop residue on the soil surface year-round, while growing crops on preformed ridges alternated with furrows covered by crop residue. In seasonal tillage, one manages the amount, orientation, and distribution of crop residue maintained on the soil surface between harvest and spring tillage operations that bury the residue. Seasonal tillage offers very little financial benefit over conventional tillage other than from a conservation standpoint. By tilling in spring rather than in fall, one will avoid the interest on operating capital that would accrue during winter.

Each crop-residue management system can be used in an overall scheme that protects the soil resource to the level required for conservation compliance and continued eligibility for USDA benefits. At the same time, each system has unique economic impacts. These and other benefits can be defined as both onsite and offsite benefits. Onsite benefits include yield or productivity maintenance through erosion reduction and improved moisture conservation; improved soil tilth; better water quality; and cost reductions of labor, fuel, and machinery. Offsite benefits accrue as a result of reducing the movement of sediment and the associated filling of reservoirs and stream channels. This also reduces the movement of chemicals and fertilizers that are major agricultural pollutants of water in the Northeast and Appalachia.

Evaluating Crop-Residue Management Systems

The onsite or onfarm economic impacts of the systems listed above may be estimated from partial budgets. This procedure is useful when a change being considered affects only part of the total farm business and has a relatively small

impact on the total farm. It is an approach for calculating maximum profit points and for looking at the probable results of many alternative actions, including crop residue management. Here, only the factors that change are considered.

In the following comparisons, each of the crop-residue management systems discussed above is compared to a typical previous system, referred to as *conventional tillage*. The budgets used in generating these comparisons were developed with the Cost and Return Estimator (CARE) used by NRCS.

CARE is a database and menu-driven crop budget generator that NRCS often uses with individual landowners in planning conservation. CARE is an accounting model in which estimates are made of cost and returns for crop enterprises. Quick Budget, a component of CARE, is a module in which information in the main CARE dataset is used to compare the economics of going from conventional tillage to the four crop-residue management systems that have been used on significant acreages in the Northeast and Appalachia.

In the following comparisons, labor is valued at the market rate for hired agricultural labor in the Northeast and Appalachia. Returns to management capture labor benefits of the actual producer. Machinery cost is the per-acre cost in repairs, depreciation, and other fixed costs. Yields are not changed. Studies show that yields do not vary significantly in the short run, except in moisture-short conditions. The impacts of tillage and residue management on long-term yield are discussed in chapter 15.

Comparisons of Crop-Residue Management Systems for the Northeast and Appalachia

The results of comparing a crop-residue management system with a conventional system are displayed below. In these tabulations, the (+) indicates a positive monetary advantage in converting from conventional tillage to the crop residue managements. The (–) indicates a financial loss.

No-Tillage Versus Conventional Tillage: Per-acre net gain or loss in corn grain production in Pennsylvania

<u>Item</u>	<u>Total gain/loss (\$)</u>
Net return	+ 26.10
Labor	+ 4.50
Fuel	+ 3.60
Material	– 9.40
Machinery	+ 26.40
Interest (operating capital)	+ 1.00

No-Tillage Versus Conventional Tillage: Per-acre net gain or loss in corn grain production in Virginia

<u>Item</u>	<u>Total gain/loss (\$)</u>
Net return	+ 9.88
Labor	+ 4.47
Fuel	+ 3.86
Material	– 18.53
Machinery	+ 20.34
Interest (operating capital)	– .27

No-Tillage Versus Conventional Tillage: Per-acre net gain or loss in corn silage production in Maine

<u>Item</u>	<u>Total gain/loss (\$)</u>
Net return	+ 15.60
Labor	+ 5.00
Fuel	+ 1.00
Material	0.00
Machinery	+ 9.00
Interest (operating capital)	+ 0.60

Mulch Tillage Versus Conventional Tillage: Per-acre gain or loss in corn silage production in Connecticut

<u>Item</u>	<u>Total gain/loss (\$)</u>
Net return	+ 18.60
Labor	+ 4.30
Fuel	+ 3.34
Material	0.00
Machinery	+ 10.36
Interest (operating capital)	+ 0.60

Mulch Tillage Versus Conventional Tillage: Per-acre net gain or loss in corn silage production in New York

<u>Item</u>	<u>Total gain/loss (\$)</u>
Net return	+ 16.70
Labor	+ 2.90
Fuel	+ 0.90
Material	0.00
Machinery	+ 12.50
Interest (operating capital)	+ 0.40

Ridge Tillage Versus Conventional Tillage: Per-acre gain or loss in corn grain production in Pennsylvania

<u>Item</u>	<u>Total gain/loss (\$)</u>
Net return	+ 20.85
Labor	+ 2.90
Fuel	+ 2.35
Material	– 9.40
Machinery	+ 24.00
Interest (operating capital)	+ 1.00

Seasonal Tillage Versus Conventional Tillage: Per-acre gain or loss in corn grain production in Virginia

<u>Item</u>	<u>Total gain/loss (\$)</u>
Net return	+ 1.17
Labor	0.00
Fuel	0.00
Material	0.00
Machinery	0.00
Interest (operating capital)	+ 1.17

Partial budgets from cases in four other northeastern states indicate that various forms of crop residue management not only improve profits but also save labor and fuel.

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7 Nutrient Management

K.L. Wells and D.B. Beegle

Conservation tillage has become a widely used practice for crop production in the Appalachian and Northeast region. Over a third (36 percent) of the total planted acres in this area was planted with such practices in 1991. The most common conservation-tillage practice used was no-tillage, which was used on 7.96 million acres of the 22.28 million planted acres. Mulch tillage was used on another 3.46 million acres, and ridge-tillage was used on only 7,350 acres. No-tillage is the major conservation-tillage practice used on several crops; it is used on 53 percent of the conservation-tillage acres in corn, 74 percent in soybeans, and 59 percent in forages. In contrast, 39 percent of the conservation-tillage acres in small grains were no-tilled.

This chapter summarizes what is known about crop nutrient management under conservation-tillage conditions in the Appalachian and Northeast region. To put this into proper perspective, we need to understand a few basic concepts that have evolved from conservation-tillage research.

Basic Concepts

Redistribution of Nutrients

In conventional seedbed preparation where a plowsole is inverted annually and mixed repeatedly over a period of time, nutrients become somewhat uniformly mixed to the depth of plowing. In contrast, conservation-tillage techniques result in a buildup of nutrients near the soil surface. Figures 5 and 6, taken from University of Minnesota research, illustrate this phenomenon for phosphorus (P) and potassium (K). As shown, the less physical tillage that takes place, the higher the buildup of P and K (and other immobile nutrients) just below the surface. The same thing occurs with nitrogen (N) as a function of the surface buildup of organic matter with no-till. Chisel plowing or disk tillage moves organic matter, P, and K a little more deeply into the soil than does no-tillage.

Acidification of Soil Surface

No-tillage results in rapid acidification of the top 1–2 inches of soil because of accelerated biological decomposition of surface residues at the soil/residue interface and because of nitrification of surface-applied acid-forming N fertilizers and manure. This is more likely to reduce yields of no-till corn than most other annual crops. The causes are (1) the increased likelihood of aluminum (Al) and manganese (Mn) toxicity and (2) the poorer weed control associated with increased adsorption on clay and with faster degradation of triazine herbicides such as atrazine and simazine.

Soil Moisture Content

Because of less surface evaporation and better infiltration of rainfall, usually 15–25 percent more soil water is available during the growing season with no-till than with conventional tillage. This and other factors affecting water-use efficiency are discussed in detail in chapter 5.

Accelerated Biological Activity at Surface

As expected from more moisture and accumulation of a concentrated layer of organic residues at the soil surface, the surface microbial activity is greater in no-tilled soils than in conventionally tilled soils. Greater numbers of both aerobic and anaerobic bacteria have been measured under no-till than under conventional tillage. Even though large numbers of aerobes are present, the relatively large presence of anaerobes, together with a high concentration of organic materials and a higher soil moisture content, results in a greater potential for anaerobic conditions to occur in no-tilled soils than in conventionally tilled soils.

Soil Temperature

Due to the insulating effect from the surface mulch of killed sod, killed small grain, or previous crop residues, the soil temperature will change more slowly under no-till conditions. This results in cooler soil temperatures—particularly during the early part of the growing season—and much less diurnal fluctuation.

With these concepts in mind, one may reach a better understanding of nutrient management in a conservation-tillage system. In the following discussion of nutrient management, no-tillage is emphasized.

Nutrient Relationships

Nitrogen

When added to soil as anhydrous ammonia, manure, urea, or ammonium nitrate, the ammonium form of N oxidizes to nitrate in a relatively short time. The nitrate moves freely with soil water except in subsoils with high iron-oxide content and low pH. Even in such subsoils, the mobility of nitrate is roughly half that of water, so nitrate is still subject to movement with the soil water. In addition, nitrate can be lost by denitrification if the soil moisture remains above field capacity for several days and if organic matter is present. Such conditions are usually found in soils with sticky clay subsoils or other restrictive subsurface layers that retard the rate of water movement through soil.

Since nitrate tends to move with the soil water, it is necessary to understand how water moves under no-tillage compared with its movement under conventional tillage in

order to better understand N movement in no-tillage. There are two basic differences: First, water infiltration commonly increases under no-tillage, so the average nitrate movement in some soils is deeper with no-tillage. Second, under no-tillage, there is much less evaporation of water from soil and thereby less movement of nitrate toward the soil surface during periods of surface-water deficit. Under no-tillage on well-drained soils, there is the possibility of substantial nitrate loss by leaching soon after planting and before the plant is large enough to remove significant N from the soil.

Denitrification of nitrate can result in sizable N losses from soils that may percolate water slowly or remain saturated with water for more than a few hours after N application. Although greater denitrification losses are expected on imperfectly-to-poorly-drained soils than on well-drained soils, denitrification can also take place on well-drained soils under no-till. This is probably due to increased soil-moisture content and greater microbial activity (particularly anaerobic bacteria) under no-till. Both are a result of the decreased evaporation and the surface mulch in no-till.

To overcome this potential loss of nitrate N from no-till corn during the early growing season, fertilizer N can be applied in split application or can be delayed for 4–6 wk. This often results in a marked improvement in yield and is usually as effective as preplant application. This delayed application also allows the use of the presidedress soil nitrate test (PSNT) for corn.

Work with nitrification and urease inhibitors used at planting time on no-till corn has shown about the same effect as work with split applications. On soils with somewhat restricted drainage, the response from late application is better than that on well-drained soils. This suggests that denitrification is the major source of fertilizer N loss from such soils.

Another important factor in N nutrition is the rate of mineralization of organic N during the decomposition of fresh crop residues. When soils are plowed and otherwise disturbed, a great increase in soil nitrate may be produced, probably because soil nitrifiers and organic matter are mixed with the soil. Because this mixing action of residues into the plow layer does not occur in no-tillage, the rate at which nitrate is produced under no-tillage is considerably lower. This slower mineralization of N is of particular concern when a legume residue is counted on to supply most (if not all) of the N needs of a following crop. Research has shown that although the rate of N release is slower in no-till, it is rapid enough to keep up with the need of the corn crop through the season. Consequently, the response of a no-till corn crop to N following a legume is usually similar to that in conventional tillage.

Application of N below the surface residue layer of no-till has been shown to improve fertilizer N efficiency, presumably by reducing this immobilization and by reducing losses

by ammonia volatilization. There is greater potential for the loss of N by ammonia volatilization from urea and urea-containing sources of N if they are applied on the surface in no-till systems. This includes UAN (nitrogen solution) and manure. The initial reaction of urea in the soil results in the production of free ammonia and ammonium ions. If the urea source is incorporated, this ammonia is adsorbed in the soil as ammonium ions, and there is little loss. However, if the urea is not incorporated by tillage or rainfall, there is the potential for losses as high as 30 percent of the applied N within a week. Thus, if possible, urea should be incorporated in conservation-tillage systems. In no-till, the loss will be minimized by injection of the urea-containing material or by application just before one-half inch of rain. Also, surface banding can reduce the loss somewhat compared to the loss from broadcasting the urea source. Other N sources such as ammonium nitrate and ammonium sulfate are not subject to volatilization losses in acid soils. So if the price is right, using one of these materials in no-till will also minimize this potential loss.

Despite the potential for greater N inefficiency in no-till corn, N fertilization at recommended rates in no-till usually results in equivalent yields or yields that are greater than those from conventionally tilled corn. It is assumed that this is due to the more efficient use of fertilizer N (at recommended rates) than in conventionally tilled corn, due to more available water. The long-term effects of tillage on N in soils are discussed in chapter 15.

Phosphorus and Potassium

When applied to soil, phosphorus (P) and potassium (K) move very little from the site where they first contact the soil; for this reason, they are often called *immobile* nutrients. When P is applied to soil, it reacts strongly and results in forms of P that are less soluble than are most sources of fertilizer P used. Because of this, crops rarely take up more than 15–5 percent of the P applied in any given year. The degree of P fixation to unavailable forms is closely related to the soil acidity. When soil pH is maintained at 6–7, plant-available calcium (Ca) phosphates and aluminum (Al) phosphates are formed that are more available to plants than are the iron (Fe) phosphates, which form at soil pH levels below 6. If soil pH exceeds 7.0–7.5, P will react with Ca to form Ca phosphates, which are much lower in solubility than are phosphates formed at pH 6–7.

Because P is such an immobile nutrient, there is little leaching, so surface applications of P remain near the surface. This raises the concern that the P may be positionally unavailable for adsorption by plant roots. However, broadcast surface applications of P in no-till have been shown to be efficient because of the following: (1) Plant roots feed where the soil surface contacts the mulch in no-tillage. (2) A broadcast surface application in no-till is actually a horizontal band coincident with organic matter

from the crop residue; this application results in less soil fixation of fertilizer P and more relatively mobile organo-phosphate, compared to results when applications are mixed into the soil.

Other immobile nutrient cations such as K, Ca, and magnesium (Mg) react with soil cation exchange sites and, although held somewhat strongly, can still move slowly through the soil, particularly under leaching conditions and in soils with low cation exchange capacity. When N as nitrate is leached from the soil, it does not move by itself. Because electroneutrality must be preserved, an equivalent amount of cation is always removed. The most abundant cation in most agricultural soils is Ca, which is the cation that moves down through the profile in the largest amounts when nitrate is leached. The downward movement of these nutrients is also aided by the acidification from ammoniacal forms of N. This was apparently taking place in the long-term no-till system referred to in figure 17 (ch. 15).

Potassium is nearly always present in soil in small quantities relative to Ca. On friable well-aerated soils, tillage has very little effect on either the amount of K needed or the methods of K application. When applied to the surface in no-tillage, K is found to be distributed with depth in about the same way as K applied to the surface and disked in under conventional tillage. Research indicates that changes in K fertilization are not required when no-tillage is practiced unless the soil has characteristics that inhibit root growth, such as coolness or compaction.

Concepts regarding broadcast and banded P and K in no-tillage differ somewhat from concepts about similar application in a conventionally tilled seedbed. Many years of studies since the 1930's on the placement and rates of immobile nutrients in infertile conventional seedbeds have shown an advantage from band placement. In that method, as seeds germinate and begin growth, the roots intercept the fertilizer band. This "band response" of placement has been found to be most effective when the plant-available supply of the nutrient applied is low. However, when plant-nutrient-availability levels in soils are increased, the importance of band placement decreases. The current commonly accepted concept is that with moderately high or high levels of plant-available nutrients, banding has no particular agronomic advantage over broadcasting fertilizers. As previously explained, a notable exception is in soils that have a root-growth-limiting factor such as compaction or coolness. Several experiments have shown that a band placement of fertilizer in or near the row can improve the crop growth on such soils. Thus, where starter fertilizers are needed, they are as important in conservation-tillage systems as they are in conventional-tillage systems, and possibly more so.

The principle involved in appropriate fertilizer placement of immobile nutrients is as follows; Broadcast application followed by tillage mixes the applied nutrient more thor-

oughly with the soil. If the soil tests low in availability of that nutrient, most likely the subsequent soil-fertilizer reactions will convert the applied nutrient into less soluble forms; this results in poor use efficiency for the fertilizer applied. With banding, there is much less mixing of the applied fertilizer with soil, and the availability of the applied nutrient remains higher for longer than if it were mixed with soil. Because of this, lower rates of fertilizers can generally be used in band applications than in broadcasting and mixing, without affecting crop yields.

The notable feature of no-tillage is that soil is not disturbed by plowing or disking, so there is no practical way of increasing the fertility level through the plow layer by plowing down or disking in the fertilizers. If fertilizers are needed, they must be broadcast onto the sod, mulch, or soil surface, or they must be banded with a planter fertilizer attachment. Although planter fertilizer attachments are available, many producers do not purchase or use them because they slow the planting operation. For this reason, some growers' concern about no-tillage is related to the efficiency of broadcast surface applications of fertilizers. Despite these concerns, studies have shown that surface-applied immobile nutrients generally perform adequately.

The apparent reason for this adequate performance is that under no-tillage, the surface mulch maintains sufficient surface soil moisture for root growth and subsequent nutrient uptake at the soil-mulch interface. Another important factor is that a topdressed application that leaves fertilizer such as phosphate lying on crop residues will reduce some soil-fertilizer interactions that immobilize nutrients. For these reasons, under the relatively moist conditions of the Appalachian and Northeast region, surface applications of fertilizer are often almost as good as band placement.

Manure is a very significant source of nutrients on many farms with confined livestock or poultry enterprises in the Appalachian and Northeast region. For manure to be effectively used as a source of nutrients, the content and behavior of the nutrients in manure must be known. Manure's nutrient content is best determined by analysis of a representative sample. Published average values provide an estimate of nutrient contents, but actual individual analyses may vary from the book values by a factor as great as 2.

The N in manure can be divided into two functional fractions: an unstable organic fraction and a stable organic fraction. The unstable organic fraction is mostly urea and thus is mineralized very rapidly to ammonium and subsequently nitrified to nitrate. These mineral forms of N behave as described in the earlier section on N relationships in conservation tillage. However, there are some unique interactions between manure N and conservation-tillage systems. Because most of this N is urea, there is a large potential for N loss through ammonia volatilization,

particularly in a no-till system, if the manure is not incorporated. The N availability from unincorporated manure is generally less than half the N availability from manure that is incorporated immediately. The fraction of the total manure N available to the crop, in relation to time until incorporation, can be estimated using locally determined manure N availability factors from each state agricultural college. This adjustment is especially important for conservation-tillage systems where the manure is not completely incorporated.

Incorporating manure in conservation-tillage systems does increase the availability of manure N. But accomplishing this requires a compromise. The goal of conservation tillage is to leave as much residue on the soil surface as possible, but maximizing the availability of manure N requires that the manure be thoroughly mixed with the soil. Probably the best compromise now available is injection of the manure directly below the soil surface. This seals all the manure into the soil and results in minimal disturbance of existing surface residues. As with urea fertilizer, 1/2 inch of soaking rain immediately after surface manure application will also reduce the N losses. Manure N acidifies the soil, as discussed in text above (acidification of the soil surface) and below (liming).

Because the mineral N in manure is applied along with a large amount of organic material, an additional buildup of organic matter near the surface in conservation-tillage systems will result. As noted earlier, this surface organic-matter accumulation in conservation tillage can decrease the plant's uptake efficiency due to immobilization and denitrification of added N. Injected manure has a large potential for the denitrification loss of N. If manure is injected, chemical conditions in the injection zone will be conducive for denitrification because nitrate N, organic matter, and saturated moisture conditions are usually present.

The stable organic N will slowly become available over a period of years as the manure is decomposed by soil microbes. Because this process is biological, it is very sensitive to the conditions where the manure is decaying. In reduced tillage systems, particularly no-tillage, the environment differs from that in conventional-tillage systems. Because of this, the breakdown of this organic fraction and release of the N will differ. Generally, the rate of manure breakdown is slower in reduced tillage systems because of less mixing of the soil with the manure, less aeration, and lower soil temperatures.

The P in manure is mainly in the organic fraction of the manure and thus is only slowly available to a crop. However, in the organic form, P is not readily fixed into unavailable forms in the soil like highly soluble P fertilizers. The net result is that the P in manure reacts very similarly to the P in fertilizer in building soil P levels. Thus, manure P can often be substituted for P in fertilizer on a one-to-one basis. However, because of its slow release from organic form,

most of the manure P is not available to plants in their seedling stages; so a few pounds of starter fertilizer P can be very important in helping crops get a good start in conservation-tillage systems. As with the organic fraction of manure N, the reduction in tillage in conservation-tillage systems affects the biological activity of the soil and thus the rate of organic P release. If applied at rates exceeding crop removal, manure P will accumulate in the soil and be available for uptake from subsequent crops.

The K in manure is mostly in a soluble form similar to the K in fertilizer. Thus, the K in manure can be substituted one-to-one for fertilizer K. This high solubility of manure K can result in excessive levels of soluble salts if too much manure is applied, particularly on lighter textured soils. This is especially a problem when poultry manure is applied at high rates immediately before the crop is planted. As with P, excessive application of manure K will accumulate in the soil and be used by subsequently grown crops. As discussed earlier, K management is not greatly influenced by the tillage system.

If too much nutrient is applied, it is critical that conservation practices be implemented to keep the excess nutrients in place until they are used by a following crop. As a general guideline, if conservation practices are not in place to keep soil loss below the tolerance level, "t", then excess manure nutrients should not be applied. This is a very important consideration in integrating conservation-tillage and manure-management systems.

Another factor worth noting, particularly in no-till systems, is the greater likelihood of soil compaction when manure is used, due to the traffic of loaded manure spreaders in fields. Deep chiseling, often used to loosen compacted fields, is not compatible with no-till management. So it is important to avoid compaction by not spreading manure on wet soils under no-till.

In a manure-management plan, the nutrient status of the farm fields should be assessed, and then the fields should be ranked on the basis of their nutrient deficiencies. Then manure should be applied to the high-priority fields at a rate to meet the crop nutrient requirements, but the rate should not exceed the rate that will meet the need for manure's most vulnerable nutrient.

Determining Needs for Lime and Other Nutrients

Soil Sampling

Soil testing is just as critical in conservation tillage as in any other tillage system. Properly taken soil samples that have been analyzed by reliable and properly calibrated soil-testing procedures will provide the best information for determining the lime and nutrient needs for crop production.

Regular soil tests taken at least every 3 yr, or when the crop changes in the field, are vital to a good soil fertility management program. The soil test provides information on the nutrient status of the soil, thus indicating where the greatest economic returns and the least environmental impact will occur from adding nutrients.

The major difference between soil testing in conservation-tillage and conventional-tillage systems is the sampling depth. As tillage is reduced, significant stratification of the nutrients takes place. This stratification is illustrated in figures 5 and 7 for P. Note that in figure 7, with the exception of the starter fertilizer band located about 4 inches horizontally from the corn row for conventional tillage, the P levels are fairly uniform across the row. In figure 5, moldboard-plowed systems have uniform P vertically through the plow layer. However, in no-till (also fig. 5) there is a very distinct vertical stratification: The soil near the surface has high soil-test P levels, and those levels decline with depth in the plow layer. The variation across the row in no-till may be due to residual effects of the previous starter fertilizer bands.

In contrast to the traditional 6-inch sampling depth of conventionally tilled fields, a shallower sampling is often recommended for no-tillage. Otherwise, the buildup of surface acidity and nutrient levels will be diluted and their presence will be undetected. Sampling to a depth of only 4 inches is considered more appropriate with conservation tillage. Additional sampling may be taken at depths below that, if desired, to monitor subsoil acidity and nutrient levels. In some situations, even the 4-inch sampling may not be sufficient to allow adequate description of the nutrient and acidity stratification that can occur with no-tillage. Samples taken from depths of 0–2, 2–4, and 4–6 inches will enable a much better definition of acidity and nutrient stratification in a field.

Even though research has indicated that a shallower sample may be better in conservation-tillage systems, many current soil-test interpretations and recommendations are based on research using “plow depth” samples. Since laboratories may have different sampling procedures, be sure to follow the sampling recommendations for the lab where your samples are sent so that the results will be interpreted properly. But regardless of the sampling method, it is important to be consistent. A slight variation in sample depth from field to field or from year to year can result in misleading soil-test results.

Needs for Lime

If lime is needed, the question arises as to how it should be applied, particularly with no-tillage. This concern arises because the acid-neutralization reaction resulting from lime dissolution in soil is very localized; it takes place very near the surface of individual lime particles. Because of this, the degree to which soil acidity is neutralized in a given volume

of soil is directly related to how well the liming material is mixed within that volume. This is illustrated in figure 8, where the recommended amount of limestone was applied in a continuous no-till corn system. The soil pH in the surface 2 inches of soil rapidly increased, whereas the pH in the layers at 2–4 and 4–6 inches did not change significantly until the fifth year of the experiment.

Lime *cannot* be mixed into the soil in two important production systems: perennial sodland used for pasture or hay, and continuous no-till crop production. Studies of both situations show that the crop yield after topdress application of lime onto the surface was greater than the yield after no liming.

A number of liming techniques have been proposed to prevent the formation of the acid zone at the surface of no-tillage soil. Both larger total amounts of lime and smaller, more frequent applications have been suggested. However, research indicates that both practices are unnecessary. Lime added at rates based on soil-test results was sufficient to maintain a proper pH through the plow layer. The pH correction came relatively quickly, because lime was placed at the soil surface, where most of the acidification in no-tillage soil occurs. In situations where the plow layer is very acid, incorporation of lime to correct the pH should be considered before going to a no-till system.

The long-term effects on the pH of surface soil and subsoils from applying lime or ammonium fertilizer and from leaving residues on the soil surface are discussed in chapter 15.

Need for Nitrogen

Except for a few notable exceptions, soil testing for determining crop N requirements is not used in the Appalachian and Northeast region. This is because N is extremely mobile, its various chemical forms are dynamic in soils, and researchers have had little success in interpreting soil N measurements. The cropping history and the soil-drainage characteristics are often considered in determining the N rates to be used for corn. If the field to be no-tilled is now in sod, there will be slow mineralization of a significant amount of organic N through the growing season after the sod is killed. For this reason, less fertilizer N would be required than for a field that is in continuous no-till cropping. If the sod contains legumes, even less fertilizer N would be required. Studies in these regions have described the use of soil and climatically adapted legume species to supply some of the nitrogen for the corn that follows. Hairy vetch has been effective in supplying N for corn. Soil-drainage characteristics also affect the rate of N required. This is because of N losses that can occur from either leaching or denitrification.

Some states in the Appalachian and Northeast region have recently recommended the use of a presidedress soil nitrate

test (PSNT) for corn to determine the amount of fertilizer N, if any, that would be required. The PSNT has been shown to be very effective in predicting the N response and in providing some improvement in the N recommendations for corn in some states in the Appalachian and Northeast region. This test has been especially useful where manure provides a significant but variable amount of N to the system. Research has shown that the PSNT works in manured conservation-tillage systems. However, the PSNT is not a good indicator by itself of fertilizer N need where corn is no-tilled into a legume residue. This is due to the major contribution of the legumes to the nutritional needs and also the slower mineralization rate of the legume residue in no-till systems.

Needs for Phosphorus and Potassium

The amount of P and K to apply should be determined by the residual available P and K content of the soil. Soil-testing procedures that have been fine-tuned for the local soil and climate can be used to determine the levels of residual P and K. The grower can then determine the amount of additional fertilizer needed for the crop to be grown. Most Land Grant Universities and many commercial analytical laboratories provide fertilizer recommendations to growers.

Needs for Secondary Nutrients and Micronutrients

The need for fertilization with secondary nutrients (calcium, magnesium, sulfur) and micronutrients (zinc, copper, manganese, boron, molybdenum, chlorine) is much more site-specific than is the need for fertilization with the primary elements (N, P, K). There is rarely a need for Ca solely as a plant nutrient, and the liming of acid soils keeps the levels of plant-available Ca well above those needed for just plant growth. Fertilization with Mg is sometimes needed for good plant growth, particularly on sandy soils. There is also a need for S under some soil-crop conditions. This need may become more common as responses to the Clean Air Act remove more S from the rain. Extension services and associated Land Grant Universities are usually aware of localities where these nutrients may be needed and can recommend the necessary rates.

Sources of Nutrients

Nutrient sources commonly used in conventional seedbeds perform just as well in no-tillage. Because of the limitations of application machinery, it has been more difficult to apply anhydrous ammonia under no-till. But in recent years, satisfactory anhydrous applicators were developed for use in grass sods and mulches. Studies have shown that losses of N from urea under no-tillage are often higher than losses when other N sources are used. This loss of N in no-till is related to minimal soil contact or maximum mulch contact when

the urea is applied. Animal manures can also be a valuable source of nutrients. Their use is discussed in detail in the Summary.

Summary

No-till and other conservation-tillage practices are important and widely used components of major crop-production systems in the Northeast and Appalachian region. However, not all nutrient-management practices are the same for these conservation-tillage systems as for conventional-tillage systems. No-till systems create a surface mulch of crop residue that results in more available water, surface acidification if not limed, and cooler early-season root-zone temperatures. Under continuous conservation tillage, nutrients become stratified, with high concentrations developing in the upper 1–3 inches of soil. Because of the moisture modification of the root zone under no-tillage, there is a potential for higher yields of corn. This potential and the incorporation of N in the increasing organic-matter contents in most no-till systems justify the need for slightly higher amounts of available N in no-till systems. However, the increased soil moisture under no-till can cause more denitrification, leaching, and immobilization of N. This intensifies the need for use of N-conserving practices.

Surface-broadcast applications of P and K fertilizers have been shown to be effective except under conditions where other factors restrict root growth. Also, routine surface-broadcast applications of lime at rates indicated by soil test have been shown to be effective in preventing development of an acid layer in the top 1–2 inches of soil in fields continuously no-tilled to corn. Soil samples should be collected according to the guidelines of the testing laboratory being used because the depth will vary, according to calibrations used by the lab. A soil sampling depth of 0–4 inches is generally considered adequate for no-till fields.

Manure can be effectively used as a nutrient source in conservation-tillage systems. However, because the availability of manure N is sensitive to the method of application, the efficiency of N recovery under the method used must be accounted for in determining the contribution of manure N to the total crop needs in these reduced-tillage systems. Since manure nutrient content usually doesn't exactly match the crop requirements, an excess of P or K is often applied. Because of this, conservation practices are critical to keep these nutrients in place until they can be used by a following crop in the crop rotation. A manure-use plan should be based on analysis of the manure's nutrient content and the crop requirements as determined by soil testing. It is important to prioritize one's farm fields for manure application to achieve the maximum return from manure nutrients with minimal environmental impact.

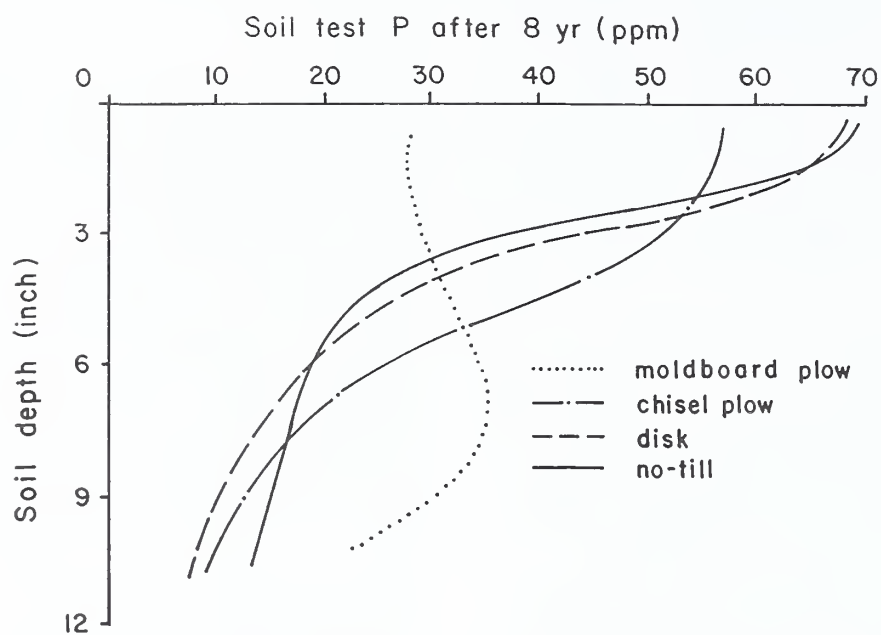


Figure 5. Effect of tillage system on distribution of soil-test phosphorus levels

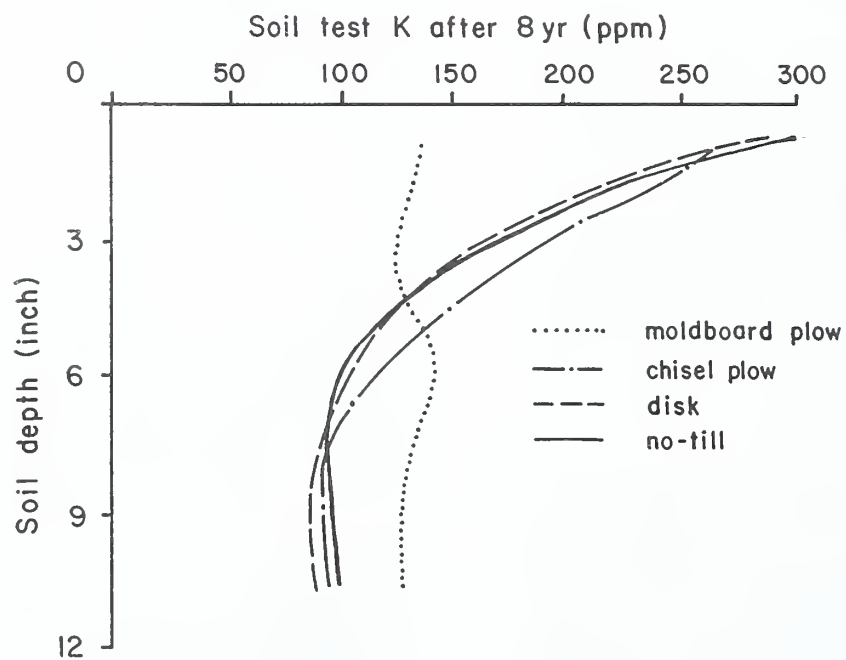


Figure 6. Effect of tillage system on distribution of soil-test potassium levels

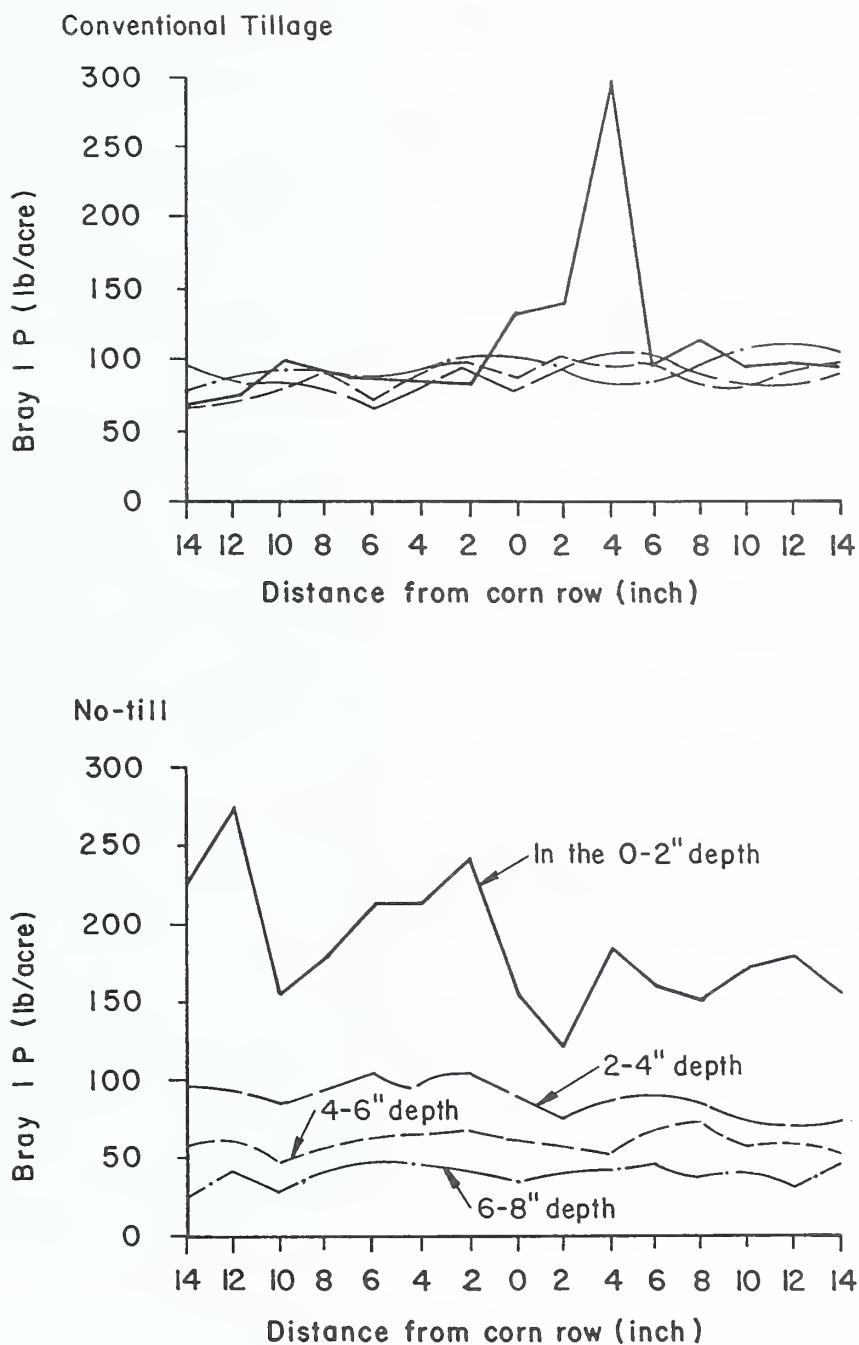


Figure 7. Distribution of Bray 1 soil-test phosphorus levels by depth across the corn row for conventional corn and no-till corn

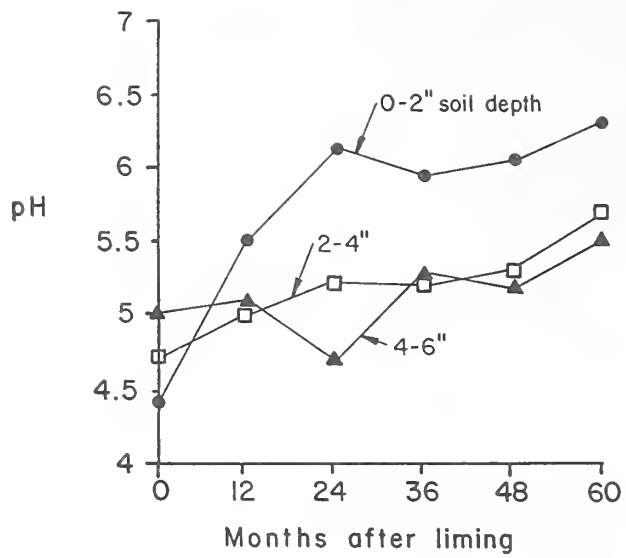


Figure 8. Change in pH in no-till corn after application of 3 tons limestone per acre

8 Effects of Crop Residue Management on Water Quality

C.W. Honeycutt and J.M. Jemison

The Appalachian and Northeast region of the United States is diverse in geology, soils, climate, and land use. Precipitation exceeds evaporation for most of the year in this region, resulting in abundant water resources. Surface water is the most apparent water resource. However, surface water and groundwater are intimately connected, with over 70 percent of the region's total streamflow fed by groundwater.

Crop residue management can significantly impact water quality in this region by regulating the transport of soil, pesticides, and nutrients to surface water. The inputs of pesticides and nutrients to groundwater are likewise influenced by crop residue management. In this chapter, we describe relevant processes and principles for understanding the effects of residue management on movement of soil water, pesticides, and nutrients to surface water and groundwater. Research results on these topics are also included. We hope this approach will allow growers to apply these principles to their specific cropping situations to sustain or improve water quality.

Surface Water

Erosion and Runoff

Individual soil particles (sand, silt, and clay) are held together into units called aggregates. Soil aggregation is important because the air spaces between aggregates are avenues for water movement. Soil aggregation therefore influences runoff and erosion. The impact of raindrops can dislodge soil particles that were previously held together as aggregates. These dislodged particles can form a crust, resulting in less water infiltration and more runoff. Higher runoff has a greater erosive force and may cause more erosion.

Crop residues help reduce the impact of raindrops, thereby reducing the aggregate disintegration and surface crusting. Residues also increase the roughness of a soil surface. These factors reduce the soil-particle detachment and runoff velocity. The volume of runoff may also be reduced because the increased roughness helps hold water on the soil surface and increases the opportunity time for intake. Residues also promote biological activity in soils, which helps to build soil aggregates. Earthworms and other mesofauna that feed on decomposing residues also burrow in the soil, thereby providing new avenues for infiltration.

These effects mean that conservation-tillage practices that maintain surface residues will usually reduce soil and water losses compared to those under conventional tillage (generally consisting of moldboard-plow tillage followed by one or more diskings). However, it is important to realize that these reduced losses are not the result of a tillage implement; instead, they are the result of the crop residue. For example, multiple passes with conservation-tillage implements can eventually bury surface crop residues and significantly reduce the benefits derived from the conservation tillage. The effects of conservation tillage also depend on such factors as crop species and time of tillage. Crops providing minimal surface residues (such as soybeans and potatoes) may provide minimal benefit. Soil-surface roughness resulting from fall tillage may be reduced by springtime. Crusting may also occur by spring, resulting in some runoff and erosion despite the use of a conservation-tillage implement.

Conservation tillage usually reduces runoff by 10–50 percent of that observed after moldboard plowing. Studies conducted in Ohio, Maryland, and Pennsylvania have reported runoff under no-till for continuous corn to be only 4–19 percent of that observed under moldboard plowing. Other researchers have reported similar runoff volumes for no-till and moldboard plowing. However, in documented cases, runoff from no-till has been higher than runoff from moldboard plowing. Yet even in these situations, sediment (that is, erosion) in the runoff is much less for no-till. The suggested 30-percent residue-cover minimum for conservation tillage generally reduces soil loss by about 50 percent of that found for moldboard plowing.

This wide range of research results may be alarming at first glance. However, the results serve to underscore the wide variation in soils, climate, topography, cropping systems, and sometimes research methods that affect study results. Descriptions of some of these factors are provided in other chapters. It is hoped that understanding how each crop-residue management system affects water quality will facilitate adapting a system to your specific situation.

Pesticides

Erosion and runoff can directly influence pesticide transport to surface water. Several properties of pesticides are important. Pesticide properties that affect their mobility in soils are persistence (how long the pesticide remains in the soil), solubility (how easily the compound is dissolved in water), and sorption (how tightly the chemical is bound to soil).

The reduced erosion associated with residue cover should result in reduced losses of sediment-carried pesticides. This should occur for pesticides that are strongly sorbed to soil, such as glyphosate and paraquat.

The reduced runoff in conservation tillage may also reduce pesticide losses to surface water. Researchers in Kentucky found higher atrazine concentrations in the runoff from no-till than in moldboard-plow study plots. However, atrazine loss was greatest from moldboard plowing, followed by chisel plowing and then no-till, due to the lower runoff volumes in the chisel-plow and no-till systems. A 5-yr study in Pennsylvania reported 0.8 percent of applied dicamba lost in the runoff under conventional tillage but only 0.1 percent of applied dicamba lost in runoff from no-till.

As discussed in chapter 15 (long-term effects of tillage), conservation-tillage practices also generally result in higher soil organic-matter contents. This has been shown for no-till in Maryland, Ohio, and Kentucky and in several other locations outside the Appalachian and Northeast region. Increased soil organic matter enhances the soil's capacity to bind pesticides such as those noted above, thereby reducing their transport in runoff water.

Surface-soil pH also declines under no-till. Low pH can inactivate triazine herbicides. Careful monitoring and maintenance of soil pH under conservation tillage (especially the surface 5 cm of no-till) benefits the water quality by maximizing the effectiveness of a given pesticide application.

Quantity and placement are other important aspects of pesticide use in conservation-tillage systems. About one-half of conventional tillage operations are conducted for weed control. This means that the use of herbicides is often higher for no-till. Crop residues may also intercept pesticides, thereby restricting soil adsorption. Consequently, broadcast surface applications under no-till can result in greater pesticide transport in runoff. However, a lower risk of surface-water contamination has been shown with band application, particularly subsurface band application.

Growers converting from moldboard plowing to no-till are likely to encounter a shift in weed species, probably including a decrease in broad-leaved annuals but an increase in annual grass and perennial broadleaf species. Populations of insects and pathogens can also change with altered residue management. Conversion from moldboard-plow tillage to a reduced-tillage system in New York did not result in new insect pests but did result in a shift in the importance of the existing insect pests. The armyworm, a sporadic pest in moldboard-plowed corn in New York, is of primary importance for reduced-tillage in that state. Growers should monitor these changes when shifting residue-management or crop-rotation strategies, to ensure proper control measures. Crop residues (such as rye) can sometimes have an allelopathic (toxic) effect on weeds and other plants, thereby providing some weed control. Crop rotations can sometimes provide more economical pest control than can pesticide applications in cropping systems with only one crop species.

Nutrients

Phosphorus (P) and nitrogen (N) are the nutrients of primary concern for surface-water quality. Phosphorus is usually the most limiting nutrient for algal growth in fresh surface water. Nitrogen is often the most limiting element in estuarine environments. The addition of P or N in these cases stimulates algal growth. Microorganisms deplete the water's oxygen as they feed on the dying algae. This results in a poorer quality of surface water for aesthetic, recreational, metropolitan, and industrial uses.

Most N and P losses to surface water are associated with sediment transport. This is especially true for P because it is usually bound tightly to soil particles and undergoes little leaching. Thus conservation-tillage systems that reduce soil erosion should reduce N and P losses to surface water. Research in Kentucky reported higher concentrations of nitrate, ammonium, and phosphate in the runoff from no-till fields than in runoff from moldboard-plowed fields. However, the losses of these chemicals were greatest from moldboard plowing, followed by chisel plowing and then no-till, due to the lower total runoff losses from chisel plowing and no-till. The above-mentioned benefits of conservation tillage for reducing erosion and runoff are re-emphasized here for protecting the surface water from nutrient enrichment.

The method of fertilizer application can also have dramatic effects on the nutrient losses to surface water. Surface application of fertilizer increases the risk of excess nutrient loss in runoff; in contrast, subsurface placement of fertilizer can reduce the nutrient losses in sediment and runoff.

Groundwater

Pesticides

The properties that make a specific pesticide effective and attractive to a grower are generally the same properties that threaten groundwater. Pesticides that resist degradation will persist to control weeds or insects for a longer time. However, increased residence time also increases its likelihood of being leached into groundwater. Solubility is critical, especially for granular pesticides such as aldicarb, because water must dissolve the active ingredient to activate the product. However, the more soluble compounds are more likely to be leached through the soil profile and eventually to groundwater. Pesticides that are not tightly bound to soil particles are also more susceptible to leaching losses.

The persistence of a pesticide in soil is affected by the compound's tendency to volatilize into the air, its susceptibility to degradation in ultraviolet light, and its resistance to degradation by soil microorganisms. Residue management

may affect pesticide persistence because pesticides that are intercepted by residues—or not incorporated into soil (as in no-till)—are more likely to volatilize. Solubility is primarily a function of chemical structure and formulation. Sorption is also a function of chemical formulation. Chemicals with a positive charge (for instance, paraquat) are held tightly by soils and do not leach appreciably. Other compounds have no charge and are bound to soil and organic matter by weaker forces.

Researchers have studied pesticide losses from leaching in the two tillage extremes: moldboard plowing and no-till. However, little information appears to be now available for the intermediate tillage practices in the Appalachian and Northeast region. A 5-yr study in Pennsylvania reported that 0.6 percent of applied dicamba was lost through leaching under conventional tillage and 5.7 percent of applied dicamba leached under no-till. The leaching events and the leachate volumes were greater under no-till than under conventional tillage. Leaching losses of simazine, atrazine, cyanazine, and metolachlor have also been reported to be higher under no-till than under conventional tillage in Pennsylvania. Leaching losses of atrazine and alachlor in a sandy loam no-till soil in Maryland were practically negligible compared to losses in the same soil under conventional tillage.

When higher leaching losses have occurred under no-till, they have usually been attributed to the greater water infiltration under no-till. The presence of macropores (such as from earthworm channels) and their persistence due to lack of tillage are primary reasons for increased leaching under no-till. However, the rainfall amount, duration, and intensity can alter these results, as described more fully in the following section on nutrient losses to groundwater.

Controlled release formulations are being investigated that can reduce the leaching potential of many herbicides. Band application may also help reduce the herbicide amounts needed to be both effective and environmentally safe. Regardless of the tillage system, one should attempt to avoid using highly water-soluble, long-lived pesticides on coarse-textured, freely drained soils—especially those near streams or those that overlie shallow aquifers. Many of the newer postemergence and burndown types of herbicides recommended for no-till are designed to be absorbed on weed leaf surfaces and are quickly hydrolyzed or otherwise degraded if they miss their target and come in soil contact.

Chapter 15 (on long-term effects of tillage) contains a discussion of how water quality is affected by passing through soil. It is also concluded that surface runoff—diverted to infiltration and returned to the surface by springs or tile outlets—has concentrations of pesticides, pathogens, and so on, that are 1 or 2 orders of magnitude lower than those concentrations in surface runoff.

Nutrients

Most of the interest in nutrient contamination of groundwater is focused on nitrate. This is because nitrate can be converted (reduced) to nitrite in the intestine of infants during their first few months of life. High levels of nitrite can interfere with the blood's capacity to carry oxygen.

The tendency for nitrate to leach rather than be adsorbed (bound) to soil is due to the electrochemical properties of both soil and nitrate. Nitrate possesses a net negative electrical charge. Soil clays and organic matter also generally possess a net negative charge. The negatively charged nitrate is repelled from the negatively charged soil in the same way that the negative poles of two magnets are repelled. This repellency prevents nitrate from being adsorbed to soil. Nitrate remains in the soil solution and is therefore susceptible to leaching.

An important question in conservation-tillage systems is, Does the greater infiltration under conservation tillage result in increased nitrate leaching out of the root zone? Both *yes* and *no* answers have been found, indicating that other factors may alter research results.

In a Kentucky study, greater nitrate-leaching losses were observed under no-tillage than under moldboard plowing. Research in Ontario reported opposite results. A minimum-tillage corn study in Pennsylvania determined that 36 percent of fertilizer N applied at the economically optimum N rate was leached out of the root zone.

Studies in Maryland have documented nitrate leaching out of the root zone for no-till soybeans. The soil-profile distribution of nitrate was only slightly affected by different forms of tillage in a Minnesota study. That study assessed no-till, ridge tillage, chisel plowing, and moldboard plowing and concluded that nitrate distribution in the soil was more related to the climate than to the tillage system.

These contrasting research results may be largely attributed to climate. The influence of conservation tillage on the leaching losses of nutrients (and pesticides) may depend on the timing, duration, and intensity of rainfall in relation to the nutrient (or pesticide) application. For example, a heavy rain soon after the surface application of a given chemical in a no-till system can result in significant leaching losses through soil macropores. On the other hand, one or more light rains after similar application may help the chemical enter and diffuse through the soil. Subsequent waterflow through macropores may bypass much of the soil matrix, resulting in low leaching losses. Thus it is difficult to generalize about which tillage system results in more nutrient or pesticide leaching, because the timing and magnitude of rainfall in relation to the application can override the tillage effects. However, it can be stated that no-till usually results in more soil macropores, which can

serve as important avenues for water and chemical movement in soils.

Related Practices for Improved and Sustained Water Quality

Other aspects of water quality related to conservation tillage are the cropping system, nutrient management, and pest management. Some of these topics are addressed in other chapters. However, it should be mentioned here that these aspects are intimately tied to the quality of the surface water and groundwater.

For example, regardless of the tillage system, much of the nitrate leached out of plant-root zones in the Appalachian and Northeast region is leached during fall and spring. The use of cover crops during this period can significantly reduce nitrate leaching. Rye has been shown to be a particularly effective scavenger for subsoil nitrate in this region. The rye acts to absorb and recycle nitrate, which otherwise may be leached to groundwater. Another example is growing a legume hay in a crop rotation. Such residues can release significant amounts of N, which are then converted to nitrate. Following a legume hay with a grass crop (such as corn) and then crediting the legume N contribution in the fertilizer recommendation may reduce the potential for nitrate contamination.

Fertilizer applications should be based on soil tests and should reflect realistic yield goals. Soils should be sampled individually in fields that have different soil types and different histories of cropping, manure, and fertilizer.

In general, manure should not be applied to frozen soils because of their high potential for runoff. The N and P contributions from manure should be credited toward the following crop's fertilizer recommendation.

Programs of plant-tissue analysis are being used in many states. This approach can help reduce the use of fertilizer, thereby minimizing the threat of nutrient contamination of surface water and groundwater while maintaining crop yields. Presidedress soil nitrate tests are being used for corn in Vermont, Maine, Pennsylvania, Maryland, Virginia, and probably other Appalachian and Northeast states to reduce excess applications of N fertilizer.

The proper allocation of crops to different soil types and tillage systems can also affect the impact of a cropping system or tillage practice on water quality. Crops providing little soil cover should be grown on soils with low erosion potential. Highly erodible lands may be better suited for perennial forages. Lastly, significant resources are being invested in the use of constructed wetlands and vegetative filter strips to collect and, in some cases, "treat" the sediment, runoff, and subsurface water from agricultural fields.

These approaches have been found effective in many cases. However, in our opinion, such techniques should not be considered a principal cure for water-quality problems related to agriculture. Such techniques may be most appropriate where the prescribed best management practices fail to reduce the sediment or contaminant loads to desired levels. Otherwise, the two approaches represent contrasting philosophies, where one is a temporary quick fix and the other may enhance the long-term sustainability of agriculture.

Summary

It is clear that conservation-tillage systems can have a beneficial impact on surface water quality by significantly reducing the sediment, nutrient, and pesticide loads to surface waters. It also appears that no-till can have both positive and negative effects on groundwater quality. The direction and magnitude of these effects depends at least partly on the timing, intensity, and duration of rainfall in relation to the nutrient and pesticide application. We may not be able to adequately predict rainfall, but incorporating conservation tillage into your cropping system along with appropriate nutrient and pest management practices should help ensure beneficial effects on surface water and groundwater quality.

9 Soil Compaction and Soil-Structure Degradation

H.M. van Es and R.L. Hill

Crop management practices, including tillage, directly or indirectly affect the physical status of soils. One objective of tillage, after all, is to provide a soil environment that is conducive to seedling establishment, root growth, and the storage and transmission of water. In general, these conditions are attained within a well-aggregated (structured) soil with rich biological populations and low strengths.

Soil-structure degradation refers to the loss of stability of soil aggregates. *Soil compaction* refers more generally to soil densification, which is the result of both the collapse of soil aggregates and the reorientation of particles into a denser arrangement. These processes are important for their effect on the physical, chemical, and biological processes that are key to plant growth and environmental protection, including water infiltration, air exchange, soil detachment, and root proliferation. Therefore, the assessment of soil compaction should be based not only on bulk density and porosity but also on soil strength, macroporosity, infiltrability, aggregate stability, and soil-water and oxygen contents.

Types and Causes of Soil Compaction

Most natural soils—certainly those in the Appalachian and Northeast region—are looser and better aggregated in the surface horizon than in the subsoil. The surface layer is also more affected by soil and crop management practices, especially tillage. Three types of soil compaction are discussed in the following text.

Compaction of the Surface Layer

The surface layer of soil is both positively and negatively affected by the use of tillage. A positive effect occurs when tillage-induced soil shattering results in a looser surface (plow) layer, thereby relieving soil compaction. But this soil layer will subsequently settle as a result of the wetting and drying cycles or of field traffic. The short-term physical status of soil is typically referred to as *soil tilth*. *Soil structure*, on the other hand, refers to the longer-term aggregation status of soil, which generally is negatively affected by intensive tillage and row-crop production. When compaction returns during rainfall and traffic, infiltration and aeration decrease. Negative effects occur when soil breakup by tillage increases the oxidation and decomposition of organic matter, and when the pulverization of soil aggregates exposes previously protected organic matter to biological oxidation. In addition, row crops generally return

less organic matter to the soil than is decomposed in tilled soils, resulting in a net loss of the residual organic matter (such as polysaccharides and polyuronide gums) that stabilizes soil aggregates. The combined impact of these processes results in surface soils undergoing seasonal fluctuations in density due to tillage and subsequent settling, as well as experiencing a gradual loss of aggregation and densification over many years of row-crop production.

Surface-layer compaction is also directly (and instantaneously) caused by traffic. In general, compaction increases when high loads (from heavy equipment or poor weight distribution) are applied to wet soils. Most compaction (about 90 percent) is caused by the first equipment pass, although subsequent passes can cause more compaction if they occur with heavier loads or under wetter soil conditions. The depth of load penetration into the soil is a function of both the total vehicle weight and the load from one wheel or track. In the shallow layer, the direct wheel pressure is most significant. In general, loads applied to the soil are equal to the tire inflation pressure, although tire lugs and sidewalls may concentrate the pressures. Slippage of the powered wheels (typically about 20 percent) may cause additional compaction through shear deformation.

Sealing and Crusting of the Soil Surface

A thin dense layer, or surface seal, may form at the soil surface as a result of aggregate breakdown and particle rearrangement under the influence of raindrop impact. The thickness of surface seals may range from a few hundredths of an inch to over 1 inch and may greatly reduce the water infiltration and increase the runoff potential. The seals harden as they dry and are then referred to as *soil crusts*. A hard crust may prevent the emergence of seedlings, at least until the crust is softened by rainfall. Surface sealing and crusting are promoted by a lack of plant canopy and surface residue cover and by fragile soil aggregates. Typically, surface seals are more severe when the soil particle-size distribution is such that it allows smaller particles to fill the pores between the larger ones, as is especially the case with sandy loam soils. Surface crusts are disintegrated by regular tillage, but they may readily reform during subsequent rainfall. Field cultivation for weed control will break up the crusts, and resealing may be prevented if a crop canopy has been established to protect the soil from direct raindrop impact. A rotary hoe is sometimes used to break up surface crusts that have formed immediately after planting.

Compaction of the Subsoil

Dense soil below the surface layer may be the result of natural processes or human-induced processes. We distinguish subsoil compaction from surface (plow) layer compaction because soil loosening does not regularly occur at the subsoil depth and because subsoils are low in aggregate-

forming organic matter. In some areas, dense subsoils occur naturally as basal tills, tight clays, or shallow fragipans. The alleviation of natural compaction is generally expensive and may require amendments or special crops to make the change permanent.

Human-induced subsoil compaction is primarily related to the use of heavy field equipment. When a load is applied to the soil surface, the pressure gradually diverges and dissipates with depth. But heavy loads still cause relatively high pressures in the subsoil, thereby resulting in soil compaction. Studies have shown that axle loads of over 10 tons may cause compaction to a depth of 20–30 inches. So large tractors, grain-filled combines, wagons, manure spreaders, and dump trucks may cause considerable subsoil pressure. Compaction damage is greatly aggravated when soils are wet, because the wet soils deform more readily when trafficked. In addition, wet soils transmit loads to greater depths, thereby increasing the subsoil compaction (see fig. 9). A recent study in New York showed that considerable subsoil compaction may be inflicted even when the soil appears to be trafficable and workable. An additional 2- to 3-day delay after rainfall in field work resulted in significantly less compaction and higher corn yields.

Subsoil compaction is also caused by the widely used practice of plowing with one set of wheels in the open furrow. Although this practice compacts a relatively small area, repeated annual loadings under uncontrolled traffic patterns will eventually result in significant subsoil damage (plow pans), even with relatively light equipment.

Tillage implements, especially disks, may cause plow pans due to high pressures at the bottom contact points. Therefore, the disking of soils that are marginally dry may cause considerable compaction.

Effects of Soil Compaction

As mentioned, soil compaction itself is less important than are its effects on other processes, as discussed below.

Effect of Soil Compaction on Soil Mechanical Impedance

Soil densification results in higher soil strengths and resistance against root extension. But soil strength varies temporally with soil-water conditions: Dry soils are generally harder and are therefore less susceptible to root penetration than are wet soils. This is illustrated in figure 10, which shows the seasonal change in soil strength (measured with a penetrometer) at a 6-inch depth for a silt loam (glacial till) soil under no-till and under conventional-till corn production (first year after alfalfa sod). During the early growing season, soil mechanical impedance was about 2.7 MPa (megapascal) (≈ 400 lb/in²) under no-till and 1.6 MPa (≈ 230

lb/in²) under plow till. High rainfall amounts (8.8") during July (day of year 182–212) resulted in softer soils under both tillage treatments. The following dry period in August again resulted in harder soils, with soil strengths reaching 4.0 MPa (580 lb/in²) under no-till and 2.5 MPa (360 lb/in²) under plow till. It is noted that this increase is steeper under no-till.

When considering that soil strengths above 2 MPa (300 lb/in²) result in severe root restriction for most crops, it is clear that high mechanical impedance was more significant under no-till and probably contributed to lower yields for this tillage system. It can also be deduced that seasonal weather variability may greatly impact the crop's sensitivity to dense soil. Compaction effects are greater during dry periods, especially if they occur during critical growth stages such as seedling establishment. On the other hand, perennial crops that grow during the early and late part of the growing season may take advantage of wet soils with low strength and proliferate into dense soil layers. Penetration measurements on various New York soil types have shown that soil strengths are frequently above the critical level of 300 lb/in² and often reach above 600 lb/in² in subsoils during dry periods. This does not necessarily imply that root growth has completely ceased, because roots are often able to find zones of weakness and macropores, especially in fine-textured soils. However, roots are unable to effectively explore water and nutrients in the soil, because the root hairs (which generally account for most nutrient and water uptake) are unable to protrude into the hard soil aggregates.

When roots encounter high mechanical resistance, they tend to swell and initiate lateral growth, which generally results in heavily branched, short, thick roots. Reduced water availability during dry periods is probably the most significant yield-limiting consequence of soil compaction in the Appalachian and Northeast region.

Root constriction itself also reduces the growth of plant shoots. Several studies have found reduced rates of leaf expansion under high soil strength conditions. These conditions are believed to be the result of hormonal signals from the roots and to create a shoot response similar to that in drought. This growth reduction is especially significant when young seedlings encounter dense pans or are constricted by a compacted plow layer that has "hardset." The latter situation may occur in poorly structured soils under no-tillage (see fig. 10) or under other tillage practices after post-planting periods of saturation (causing soil settling), which are then followed by rapid drying.

The adverse effect of soil mechanical impedance on crop growth is difficult to assess due to seasonal variation in soil strength and moisture conditions, complex soil pore arrangements (for example, under no-till), and variable compaction sensitivity for different cultivars, genotypes, and growth stages. In addition, it is often difficult to

separate the direct effect of root constriction from the indirect effect of limited water and nutrient availability. But in general, high soil strength results in lower yields or delayed maturity of crops or both. Research plots on several soil types in Maryland and New York were under no-till production for many years, and evaluation of their soil physical properties indicated higher bulk density and soil strength values compared to similar plow-till plots. Since yields were consistently higher (Maryland), similar (New York), or lower (New York) under no-till, it is not necessarily inferred that plant growth is adversely affected by these soils conditions. Indeed, research is showing that the interactions between plant roots and soil environment are very complex; further, the effects of tillage practices are inadequately understood and depend on many factors, including soil type. In addition, it is not known whether similar responses would be observed in farmer's fields where heavier equipment is used and the traffic is less easily controlled.

It should be noted that plants have a large capacity to compensate when partially exposed to compacted soil conditions. Studies were conducted in Maryland in which silt-loam soil under corn production was exposed to axle loads of about 5 tons on one side of the row, on both sides of the row, on both sides of the row and the row itself, or on neither side of the row. Consistently reduced yields and nutrient uptake were recorded for only the condition when the row itself was trafficked. An experiment in New York using dual wheels on a planter tractor showed corn-yield reductions for only those rows that had been straddled by wheel tracks, not those compacted on only one side. It should be recognized that similar compaction conditions often occur in turnaround areas at the ends of fields, so the diagnosis of a compaction problem should not be based on observations from the field perimeter areas.

Effect of Soil Compaction on Aeration

Soil compaction decreases the number of large pores that readily drain after soil saturation. As a result, compacted soils have low air-filled porosity when wet, thereby limiting the exchange of gases between soil and atmosphere. Roots and soil fauna consume oxygen for respiration and may deplete soil oxygen levels under such conditions. For example, for the elongation of corn roots, a minimum of 10 percent oxygen is required.

Poor aeration also has indirect effects on the availability of nutrients, in particular nitrogen. A decrease in aerobic bacteria results in lower nitrification rates, and an increase in anaerobic bacteria facilitates higher denitrification rates; both situations reduce the availability of mineral nitrogen to plant growth. In some cases, higher denitrification rates have been measured in no-till than in conventional-tilled soil, especially when soils are poorly drained and dense. The

interactions between tillage and aeration may actually be very complex. Continuous macropores in no-tilled soil may provide important pathways for aeration, and the lack of residue incorporation may limit the biological activity and in turn the depletion of oxygen.

The effects of soil mechanical impedance and aeration can be combined into the concept of the *nonlimiting water range*. For a well-structured soil (fig. 11A), the upper end of this range is defined by the soil's field capacity and the lower end by the water content at which the low water availability causes drought stress. The nonlimiting water range is narrower for a compacted soil (fig. 11B), where the upper end of the range is defined by the water content at which adequate aeration occurs and the lower end by the water content at which soil mechanical impedance becomes restrictive for root growth.

Effect of Soil Compaction on Water Infiltration and Drainage

A reduction in the number of large pores as a result of soil compaction greatly reduces the soil's ability to transmit water. At the soil surface, this reduction causes lower water-infiltration rates (especially when surface sealing is significant) and increases the runoff potential during heavy rains. This in turn may have consequences for soil erosion and downstream flooding. Again, tillage plays a dual role: (1) Tillage increases water infiltration by loosening the soil; and (2) tillage promotes surface sealing through the direct exposure of soil and causes long-term soil-structure degradation, both of which reduce soil infiltrability. The relative advantages of tillage over no-tillage for infiltration depend on factors such as climate (especially rainfall intensity during periods after tillage), soil type (especially susceptibility to surface sealing), crop type, and residue cover. Rainfall-simulation studies in Maryland for two silt loam soils under plow-till and no-till management showed about 50 percent greater runoff from the plow-till systems. Although plow-tilled soils generally have greater total soil porosity, these pores are generally less continuous than those in no-till, and surface seals may form that reduce the infiltration capacity. However, the opposite has been measured for some fine-textured soils in New York where the tillage greatly increased infiltration and the stronger soil aggregates prevented surface seals.

Reduced soil permeability also decreases soil drainage, thereby delaying trafficability and increasing the problems with aeration and nitrogen availability. So soil compaction may be further aggravated when deteriorated soil drainage causes field traffic to occur on wet soils. Prolonged soil wetness also increases the susceptibility of plants to frost heaving and root diseases. Phytophthora, fusarium, and rhizoctonia are commonly cited root diseases associated with soil compaction in humid climates.

Effect of Soil Compaction on Soil Aggregation

Surface-layer compaction and reduced aggregation of medium- and fine-textured soils cause increased cloddiness after tillage, thereby providing poor planting conditions. Further tillage is often performed to create a finer seedbed. In some cases, packers may be used to crush clods into smaller-sized units, and some pulverization of the soil may occur. Such excessive tillage further enhances the oxidation of organic matter and the destruction of soil structure. In addition, soils that have been pulverized into fine seedbeds with no surface residue are extremely vulnerable to surface sealing, crusting, and erosion. If cloddy soils are seen after tillage, it is advisable to maintain high surface roughness through minimal secondary tillage and to use a conservation-tillage planter that limits soil pulverization to a narrow seed zone.

Effect of Soil Compaction on Soil Bearing Strength

Although denser soils are generally considered undesirable, they may provide better trafficability through increased soil bearing capacity. Tilled fields provide insufficient support for field vehicles when soils are wet. In contrast, trafficked areas under no-till, zone till, and ridge till are already somewhat compacted and have high cohesion, so they are often able to bear traffic loads—such as those involved in planting, field spraying, and harvesting—sooner after heavy rains. This advantage can be especially significant if a strictly controlled traffic pattern is used where all field operations use overlapping travel lanes with high bearing strength. Under such tillage systems, increased timeliness is particularly important in the northeastern United States, where the time periods for spring field work are often short.

Tillage and Compaction

Soil compaction is an important factor in determining the success of a crop management practice. Conversely, crop management practices themselves are the primary cause of soil-structure degradation and compaction. One must recognize this interrelationship when selecting appropriate management systems for erosion prevention and water-quality protection. For example, no-till practices are unlikely to be successful on inadequately drained, medium- to fine-textured soils because they are readily (or already) compacted, whereas other practices such as ridge, zone, and mulch tillage are more likely to be successful. Sometimes the lower crop yields from these practices (compared to yields from plow-tilled lands) may be outweighed by the savings on fuel and labor. In other cases, plow tillage may be the most attractive economically, but its benefits should be weighed against the environmental consequences of soil loss and sedimentation.

Susceptibility to soil compaction varies greatly by soil type. In the Appalachian and Northeast region, we can distinguish three general geographic areas for soil (fig. 12), as follows:

Area 1: The glaciated area of New York and New England, where soils have developed in gravelly and sandy outwash, medium-textured (poorly sorted) glacial till, and lacustrine clays.

Area 2: The Coastal Plain from New Jersey to Virginia, consisting primarily of soils derived from well-sorted sandy sediments with a few areas of clayey and silty (loess) deposits.

Area 3: The area from northern Pennsylvania through West Virginia, with soils developed from in-situ weathered rock on the uplands and transported (fluvial and alluvial) materials in the larger valleys. Upland soils in this area generally vary from granite- and sandstone-derived sandy loams to limestone-derived clay loams, and they are poorly sorted. Valley soils are generally well sorted and medium- to coarse-textured.

Soil Texture and Drainage Status

Fine-textured soils generally develop problems with surface-layer and subsoil compaction, because they greatly depend on good soil aggregation for root growth, aeration, and water movement. These soils are primarily found as lacustrine clays in area 1, where wet springs and short growing seasons further compound the problem. Soils with high clay contents generally have a high plasticity index (depending on clay mineralogy) and may require extended soil drying before they can be trafficked. This is especially critical below the surface layer, where the effect of evaporation is minimal and soil drying occurs primarily through internal drainage. If the plastic limit is greater than field capacity (that is, the soil is still too wet for traffic when freely drained), then soil compaction is very likely to occur. In such cases, special attention should be given to the timing of field traffic and to limiting the axle loads. These soils typically benefit from full-width tillage (plow or mulch till) to provide for good seedling establishment and root proliferation. But continued and excessive tillage will result in soil-structure degradation. For these soils, it may be appropriate to alternate relatively short periods of row-crop production and rotations of perennial crops. No-till systems are very challenging on these soils because a lack of soil disturbance results in high-strength surface layers, especially if traffic lanes cannot be strictly controlled. In addition, heavy surface mulch on these soils may exacerbate soil wetness and coldness. Zone till and ridge till are known to be more successful on these soils, although the prevention of compaction is still critical.

Sandy and gravelly soils, which are primarily found along the coastal zone (area 2) and in many valleys throughout the region, are well adapted to reduced tillage and no-till. This is due in part to their lower susceptibility to compaction of the surface layer. Rapid soil drainage and drying after rainfall also reduce the hazard of field traffic on wet soils. High amounts of surface residue will conserve the water in these droughty soils and protect them from surface sealing and crusting. Research in Maryland has shown that no-till consistently outyields conventional tillage several years after conversion. Row-crop production can be maintained for extended periods because the loss of soil aggregation is less critical.

Medium-textured soils are found throughout the Appalachian and Northeast region, but they may vary greatly in their susceptibility to compaction. This depends primarily on whether they are formed in well-sorted materials deposited by wind or water, or are formed in poorly sorted parent materials from in-situ weathering or glacial deposition. These medium-textured soils generally have low aggregate stability and are highly erodible, so they often require the use of conservation-tillage practices. Well-sorted silts, silt loams, and fine sands of fluvial, alluvial, lacustrine, or loess origin appear to maintain low soil strengths, and they are generally well adapted to conservation-tillage practices, including no-till. However, many silt loams and loams developed from glacial till (area 1) or saprolite (area 3) allow greater interlocking of the various particle sizes, so these soils may develop considerable compaction problems in the plow layer and subsoil because of this interlocking and also crusts. The poorly sorted soils tend to be less adapted to no-tillage, because high mechanical impedance may become a problem. In such cases, some kind of full-width tillage (plow or mulch till) will likely be needed to avoid yield reductions, although ridge or zone tillage may also be workable.

Soil-drainage status is a critical factor related to susceptibility to compaction in various ways: (1) Poorly drained soils compact more readily because they tend to be trafficked when wet. For many of these soils, the surface may appear adequately dry for field traffic, but high water tables may be keeping the subsoils wet. This factor may be critical during the wet fall season, when heavy harvesting equipment is often used on marginally dry soils. (2) Poor drainage causes longer periods of excessive soil wetness and exacerbates aeration problems from soil compaction. (3) Extended periods of soil saturation cause the settling of tilled soil, which may cause the soil to become hard when eventually drying. Providing adequate drainage (surface or subsurface) is critical to the sustainable management of many soils in the Northeast, because drainage reduces soil-structure degradation and compaction and makes conservation tillage more successful. Decisions on whether to grow row crops on those soils should therefore include consideration of drainage installation.

Inversion tillage may remain an attractive option on some farms in the Northeast where row crops are harvested for silage (leaving little surface residue), rotations include sod crops, and manure incorporation is required for water-quality protection. In addition, rainfall intensities are relatively low in parts of the region, which reduces the need for conservation tillage. In such cases, due attention should be given to managing *soil structure*. This may be achieved by abstaining from field traffic on wet soils, reducing equipment (axle) loads, limiting secondary tillage to maintain the integrity of soil aggregates, and using short-term crop rotations. Cover crops may provide additional soil protection and improve the soil structure. Farmers subjected to the Conservation Compliance Provision for highly erodible lands should consider additional soil-conservation practices if they wish to continue inversion plowing. In that, spring plowing is preferred over fall plowing, because it reduces erosion rates.

Ridge tillage does not provide adequate soil loosening to correct the soil compaction. So compaction should be remedied before conversion to ridge tillage. But ridge tillage does dictate a controlled traffic pattern whereby the interrow zones are “sacrificed” for good soil structure on the ridges. Compaction problems may still occur below the ridges if field traffic occurs under wet conditions. In such cases, wheel traffic will create pressure cones (under the soil surface) that extend laterally from the traffic zone. This may result in high soil mechanical impedance at 10–12 inches under the ridge. On soils that are sensitive to compaction, ridge tillage is best initiated after full-width tillage to provide a loose surface layer. Subsequent traffic should be avoided when soils are wet. Research in New York has shown that ridge tillage is attractive on a wide range of soils, especially if fields are known to be subjected to soil saturation and flooding after planting. Similarly, zone tillage provides a distinctive advantage over no-tillage by improving the seedbed conditions and seedling growth, but it does not provide adequate soil loosening to remediate the compaction of the surface layer. Although this practice has been inadequately studied in the Appalachian and Northeast region at this time, it is speculated that the effects of zone tillage on soil strength are similar to those of no-till, except for around the seed zone.

Managing Soil Compaction

Prevention

The success of a crop management system may be determined in part by the extent to which soil compaction can be prevented. Preventing surface-layer compaction from field traffic is most critical for systems involving little or no soil disturbance (no-till, zone till, and ridge till). Conventional tillage, on the other hand, may cause seasonal soil sealing as well as gradual soil-structure degradation in the surface

layer from repeated or excessive tillage. Mulch tillage generally provides the necessary soil loosening and reduces the soil-structure degradation. It is important to prevent subsoil compaction and surface sealing in all systems.

The most important approach to preventing soil compaction is abstaining from field operations during wet conditions. Compaction is also reduced by lowering wheel pressures through the use of lighter equipment, low-pressure tires, and better weight distributions. The last may be accomplished through trailed versus three-point linkage accessories, four-wheel drive (which uses the whole vehicle weight for draft), multiple axles, or tracks versus wheels. The use of dual wheels reduces wheel slippage and soil compaction in the surface layer but is not recommended on a planter tractor, because it compacts soil on both sides of some crop rows.

Compaction can also be reduced by limiting the traffic to designated lanes, so that areas outside these traffic lanes can avoid vehicle loads. A controlled traffic pattern of this sort is dictated by the ridge-till system, and the pattern can also be used effectively under no-till and zone till. To fully benefit from a system of limiting traffic, all field equipment should be compatible for using the same lanes. Many corn combines, for example, are designed to have the wheels travel over the harvested rows rather than over the traffic lanes established by the planting process. The selection of combines on this basis or axle-width adjustment may be particularly beneficial (and critical) under no-till, zone-till, and ridge-till systems. Strictly controlled traffic is generally impossible under plow-till or mulch-till systems, because previous traffic lanes become invisible after full-width tillage. Compaction can also be reduced by keeping unnecessary field traffic (such as dump trucks) to a minimum or in controlled lanes.

Soil-structure degradation can be reduced by preventing excessive tillage, especially the practices that cause soil pulverization. Conservation planters, especially those with multiple coulters, are excellent “tillage tools” by providing fine seedbeds and good seed placement in rough or untilled soil, thereby reducing aggregate breakdown in the interrow areas.

The prevention of subsoil compaction should, again, focus on avoiding wet soil conditions. Soils may sometimes appear to be dry near the surface but are actually still too wet in the subsoil. Reducing the *total* axle weight is critical for reducing vehicle pressures in the subsoil. This may be accomplished by using light equipment or better load distributions. So heavy equipment may be poorly adapted to parts of the Appalachian and Northeast region where field work is often performed on marginally dry soils. For plow-till systems, equipment adjustments may be required to keep tractor wheels out of the open furrow during plowing.

Efforts to reduce compaction from vehicle loads should include the evaluation of *all* seasonal traffic on a field, including the load factors (especially axle weight) and the expected soil conditions at the time of traffic. For example, efforts to reduce compaction from planting equipment may be futile if heavy harvesting equipment is often used on wet soils. In such a case, efforts should possibly focus on changing the harvesting procedures or improving the soil drainage.

Remediation

It may be very important to alleviate the soil compaction before converting to a conservation-tillage system, especially no-till, zone till, or ridge till. Research has indicated that the compaction caused by vehicles with axle weights of less than 5 tons is usually restricted to the upper 12 inches of soil. Soil disturbance from tillage temporarily reduces soil compaction in the plow layer, although it does not restore the natural aggregation. Subsoil compaction may be alleviated through deep tillage, although consistent positive results have been shown for only coarse-textured soils. Deep tillage on fine-textured soils may have a negative effect. Plow pans may be partially alleviated by varying the depth and type of tillage; for instance, chiseling may reduce the compaction from plowing or disking. But continued deep (greater than 10 inches) chisel tillage is not recommended, because no yield benefits are obtained and more residue is incorporated.

It has been suggested that soils under continuous no-till will occasionally require tillage to alleviate the surface-layer compaction caused by vehicular wheel traffic and natural soil consolidation. The positive effects of no-tillage on increased earthworm populations and associated burrowing and root channelling are generally obtained after many years, so remedial tillage should generally be avoided, if possible. This is because the tillage kills many worms and disrupts worm burrows; the burrows allow worms to move relatively rapidly to escape extreme temperatures, dessication, and predators such as moles.

Freeze/thaw cycles help to reduce surface-layer compaction. Tillage enhances the effect of this process by providing a loose, unconfined plow layer, which allows free aggregate movement after the formation of ice lenses. Moreover, since the zones close to the soil surface experience most of the freeze/thaw cycles, soil mixing from tillage over many years allows the entire volume of soil to receive exposure to this process. It is therefore attractive to rough till compacted soils in fall to obtain better soil structure the following year. However, this practice greatly increases the erosion potential during winter and spring. This disadvantage generally outweighs the freeze/thaw benefits, unless fall plowing is necessary for other reasons such as manure incorporation. *Frost tillage*, which is performed in winter when soils have

a 1- to 3-inch frozen layer at the surface, may be an attractive management option by providing a loose and very rough surface. It also allows the incorporation of winter-applied manure.

The seeding of perennial crops may be the most effective approach to remedy compaction. Roots that are active during the early and late growing seasons (when soils are generally wet and soft) can penetrate compacted layers. Established crops and root systems give surface protection and allow higher biological activity, thereby increasing the release of aggregate-forming substances. Fibrous shallow rooting systems (such as found with many grasses) greatly improve soil aggregation in the surface layer, while deep tap roots from crops such as alfalfa can effectively penetrate subsoils. So certain crop mixtures, as well as high-quality forage crops, may help to relieve compaction at various depths. Discussion of the long-term effects of tillage on soils are also included in chapter 15.

In conclusion, soil compaction may be an important consideration when selecting a crop-residue management system. However, the influence of soil compaction on the success or failure of a tillage practice may vary greatly. In some areas of the Appalachian and Northeast region (especially those with medium- to fine-textured glacial till and lacustrine soils), full-width tillage provides important relief of compaction and facilitates crop growth. This relief is especially significant if soils are already structurally

degraded. On many other soils, the adoption of reduced-tillage practices (including no-till) may be very advantageous. A decision on the adoption of alternative crop-management practices should be based on evaluation of their economic and environmental benefits. Another factor is the individual farmer's ability to make new farming practices operationally and economically workable. But farmers should never be discouraged from adopting environmentally sound management practices. Instead, they should be informed about the adaptability of such practices to their land resources and about the challenges they may face when converting tillage systems.

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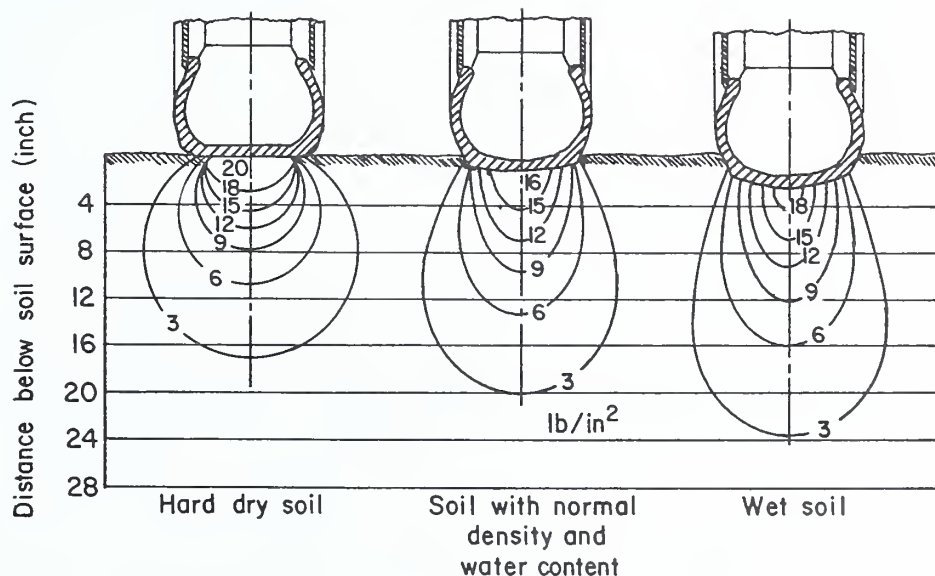


Figure 9. Effect of soil moisture on load penetration under a tractor tire. Tire size 11–28 inches; load 1,650 lb; inflation pressure 12 lb/in². Adapted from Soehne 1958.

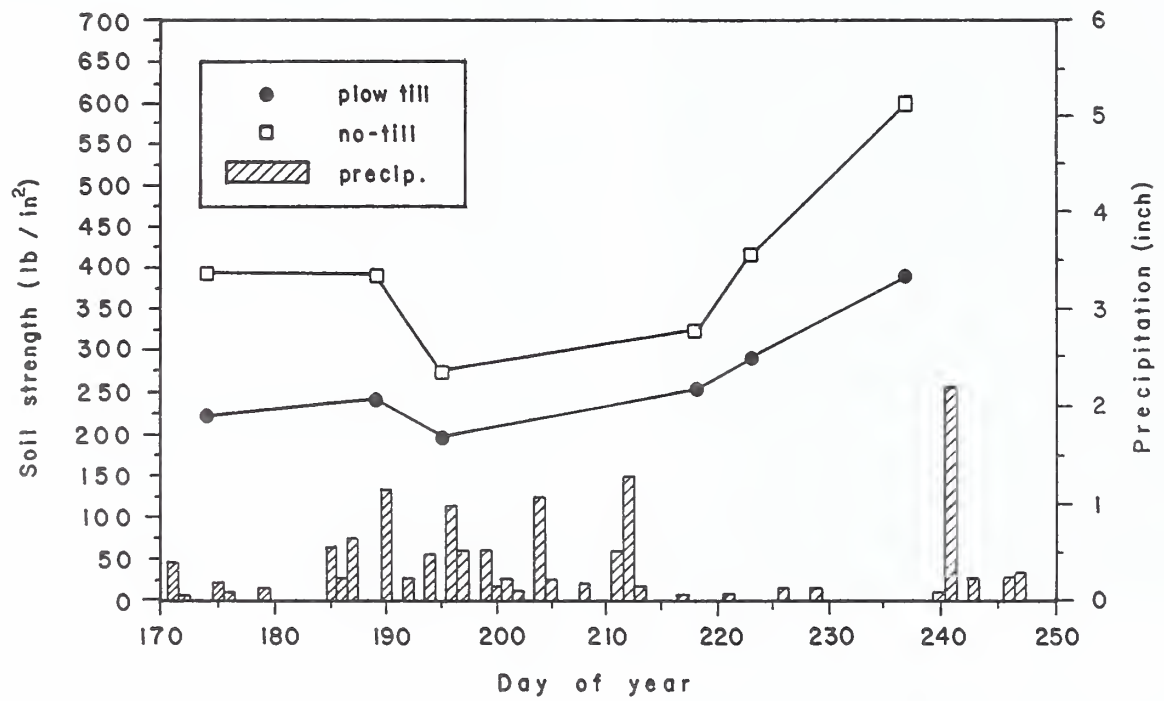


Figure 10. Soil strength at 6-inch depth under corn production during 1992 growing season at Aurora, NY

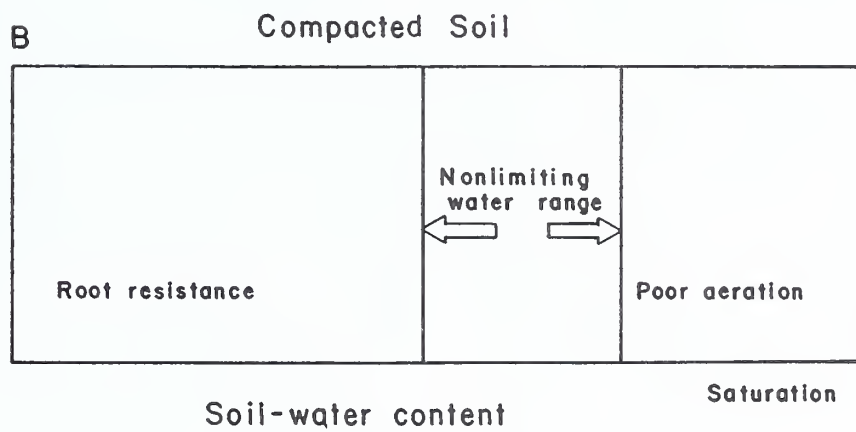
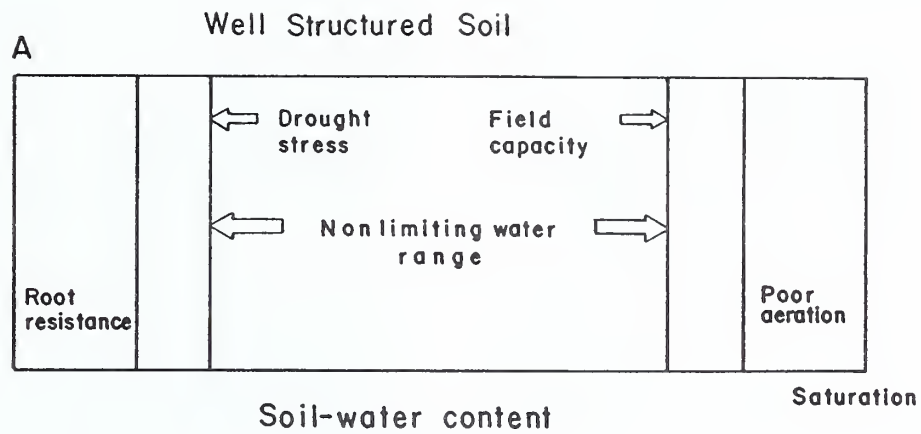


Figure 11. Generalized relationship of soil-water content and processes restricting root growth for a well-structured soil (A) and compacted soil (B). Adapted from Letey 1985.

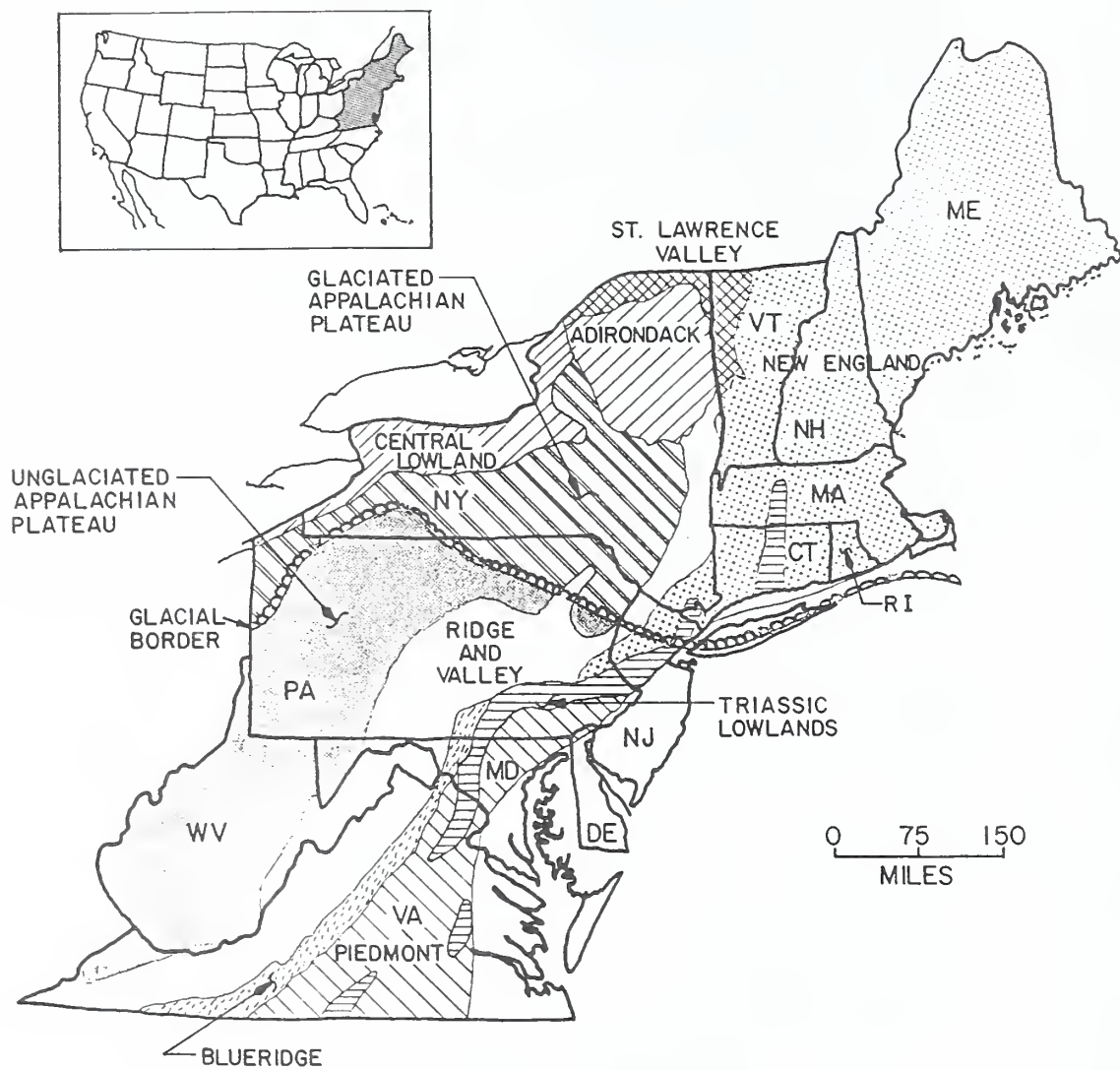


Figure 12. Physiographic provinces of the Appalachian and Northeast region. Adapted from Ciolkosz et al. 1984.

10 Reduction of Residue

J.M. Hamlett and M.H. Bagherzadeh

Crop residue management—practices that leave residues on the soil surface to help protect the soil from raindrop impact, surface runoff, and excessive erosion—have been widely adopted over the last decade and especially the past 3 yr. The amount of residue on the soil surface, or very near the soil surface, at any given time results from several factors. Most prominent are the characteristics and amount of residue produced by the previous crop, the handling of the residue after crop harvest, the extent and type of tillage conducted, and the decomposition resulting from climatic factors.

As farmers and conservationists work toward the adoption of residue-management systems with reduced tillage, the question arises, What tillage systems and practices will result in “adequate” levels (percent surface cover) of protection at the soil surface? This concern about the amount of residue cover takes on increased significance as landowners and farm operators adopt surface-residue systems to help them comply with the conservation requirements of “farm plans” implemented under the 1985 Food Security Act. The Conservation Technology Information Center (CTIC 1992) indicates that crop residue management is a primary means of achieving erosion control for highly erodible lands in nearly three-fourths of these conservation plans.

In this chapter, we provide guidance on the amount of residue cover that may be expected in the Appalachian and Northeast region of the United States in various crop, tillage, and climatic situations. Unfortunately, the field data on residue cover for this region are quite limited. As a result, most of our residue-management guidance (particularly related to residue amounts after harvest- and tillage-equipment impacts) is based on data from the midwestern and southern United States. Many conservationists, extension personnel, and farmers in the Appalachian and Northeast region question whether the published guidance material on residue cover applies to their situation. In practice, many of these same individuals adjust downward (compared with the guidance data) the amount of residue cover expected at any given time for any residue-tillage system.

Our objective in this chapter is to present a reasonable approach for estimating the residue cover that may be expected for various cropping, tillage, and climatic conditions in the Appalachian and Northeast region. Specifically, we address the following: the residue that is produced as a result of crop harvest (this is the critical starting point for any residue-management system); the impacts of tillage equipment and operations on residue cover and incorpora-

tion; and residue decay resulting from the interaction of climate, residue, and tillage factors. Because of the limited data available for the region, many of our recommendations are based on (what we believe are) reasonable adjustments to the published guidance material on residue management. Also, because our experience has centered primarily on the traditional row crops and small grains, most of our comments are directed toward residue-management systems for corn, soybeans, and small grains. This is not to say that residue-management systems for other less traditional crops (such as vegetables, fruits, and turf) are not important or not of concern. Rather, ours is a practical approach because of our limited knowledge of these “nontraditional” cropping practices, tillage systems, and residue characteristics.

Residue After Harvest

The percentage of land area in the Appalachian and Northeast region that is used for crop production is quite small (less than 20 percent) compared to that in most other regions in the country. But this land area is critically important to agricultural sustainability near population centers in the eastern United States. Much of the land that is in production is quite fragile and is subject to loss of productivity over the next 100 yr if adequate conservation measures are not adopted. The primary crops in the region range from hay, corn silage, vegetables, small grains, and orchards in the New England states to corn, corn silage, hay, soybeans, small grains, vegetables, and orchards in the middle and southernmost states. Double cropping and intercropping of soybeans and small grains are quite common in the Eastern Shore region of Maryland, Delaware, and New Jersey, whereas livestock-centered enterprises with hay, corn silage, and small grains are more common in most of the more rugged terrain in the Appalachian regions. Peanuts and tobacco production are found in the southernmost states, while orchards, vegetable crops, and other specialty crops are found nearer the urban areas in the northeast. And the residue-management systems in each area are directly related to the crops grown and the methods of crop harvest.

For much of the Appalachian and Northeast region, there was concern that many of the crops grown could not provide adequate surface residue to satisfy the conservation-plan guidelines, even under reduced-tillage systems. An early survey conducted in York County, PA, assessed the percent residue cover for various crops in spring 1991. Although the survey did not identify the tillage systems associated with each data point, it did illustrate that a substantial portion of the acres surveyed (more than 65 percent for each crop evaluated) had less than 30 percent residue cover.

This added to concern about the ability of crop residues in the Appalachian and Northeast region to keep the soils adequately covered. Many farm plans have been adjusted (with incorporation of a winter cover crop) to help farm

operators achieve the target residue-cover levels specified for compliance.

The amount of residue cover on the soil surface at any time is directly related to the amount of crop residue remaining after harvest. Crops such as corn silage, tobacco, potatoes, and other vegetable crops under typical farming practices leave little residue in the field after harvest. Other crops such as small grains, corn for grain, and hay leave the surface substantially covered by residue until the residue is harvested (typically for livestock enterprises) or until tillage is conducted. Hay, for example, will generally provide surface protection for the soil until the sod is tilled. Soybeans and peanuts leave moderate amounts of residue in the field after harvest, but these residues are quite fragile, have low carbon:nitrogen (C:N) ratios, and are therefore susceptible to rapid decomposition. Ohio researchers found that rye and wheat cover produced a more persistent mulch than did legumes, and attributed this to the higher cellulose and lignin contents and the higher C:N ratio of rye and wheat. This persistence of residue can dramatically affect the soil surface cover for various residue-tillage systems. Soybean residue, even in a well-managed system, may not provide 30 percent ground cover on many farms in the Appalachian and Northeast region. There is increasing awareness of the value of winter cover crops for protecting the soil surface in areas where residue cover is minimal or slight after harvest and where cover crops can be adequately established after harvest.

Generally, for any particular crop, the total mass of residue remaining after harvest is directly related to the yield. Table 2 shows estimates of the residue mass and percent residue cover expected for a given yield of various crops in the Appalachian and Northeast region (calculated using Renard et al., in press).

Acreage and yield data, as reported in the 1987 Census of Agriculture (U.S. Department of Commerce 1989), illustrate the dramatic differences in various crops by state. Table 3 summarizes the extent of major crop acreage and yields for various state groups in the Appalachian and Northeast region. Estimates of residue mass and percent cover that might be expected after harvest can be determined for these yield levels using table 2. In most instances, the percent residue cover after crop harvest (but before residue harvest) will be 70–95 percent. Acreage in corn silage, vegetables, and small grains, where straw is harvested for bedding, will typically have very little residue (less than 25 percent cover) remaining.

Reduction of Residue by Tillage

To comply with the Food Security Act conservation provisions, many farmers will need to know how to best use or modify tillage and planting systems so as to minimize the

residue reduction (or maximize the surface residue cover). Our discussion in this section focuses on the percent of residue cover that remains on the soil surface after various tillage operations. We assume that a reasonable amount of crop residue is present on the soil surface before tillage and that the tillage impacts the amount of this residue that remains on the surface when the tillage is completed.

The tillage process has a dramatic effect on the amount of residue cover that remains on the soil surface immediately after tillage. Generally, the amount of residue cover left on the surface is inversely proportional to the tillage-operation intensity, tillage depth, tillage speed, and degree of soil inversion. Tillage tools that tend to invert the soil will bury most of the crop residue and leave less of the soil surface protected. As the speed of chisels and most noninversion-type tillers increases, more soil is thrown into the air and comes down on top of the residue, thereby reducing the surface residue cover. Similarly, with increased depths of tillage, more residue tends to be incorporated and buried within the zone of tillage.

To retain the maximum residue on the soil surface, one should strive to minimize the soil disturbance. Such is the case with no-till, the most favorable system for retaining maximum amounts of surface residue cover. With no-till, greater than 50 percent residue cover from corn, soybeans, and small grains can be attained with average yields. Generally, a continuous no-till system will allow a buildup of surface residue cover due to the carryover of residues from previous crop years, particularly for continuous corn. At the other extreme is the moldboard-plow tillage system, which typically results in less than 10 percent residue cover on the soil surface, regardless of crop. Fortunately, the moldboard-plow system is being steadily replaced by alternative crop-residue management systems. As a result, most farm operators end up with a tillage or residue-management system that allows 10–50 percent surface residue cover immediately after planting.

The particular type of tillage implement (chisel, field cultivator, disk, and so on), specific characteristics of the soil-engaging tool (such as straight shank, twisted shank, sweep, and blade), conditions of field operation (depth, spacing, speed, and so on), number of passes with implements, and the sequencing of tillage all impact on the amount of residue cover present at completion of the tilling and planting process. Also important is the type of crop residue being considered: fragile crops such as soybeans and peanuts, or nonfragile crops such as corn and small grains.

When visually estimating the percent residue cover, farmers tend to overestimate often. Rather than discussing percent cover, it is more realistic for farm operators to think in terms of the tillage implements, planting system, and number of operations encompassed by a conservation-tillage system. The Soil Conservation Service (SCS) of USDA and the

Equipment Manufacturers Institute (EMI) separated the common crop types into fragile and nonfragile residues and estimated the amount of surface residue cover present after single operations of selected tillage implements (USDA and EMI 1992). Plant characteristics such as size of leaves and stems, density of the residue, relative quantities of residue, C:N ratio, and cellulose and lignin contents were used to subjectively classify the residue types. Table 4 lists the nonfragile and fragile crops that are common to the Appalachian and Northeast region.

The effect of tillage implements on percent residue cover is directly related to the type of residue cover and the aggressiveness (extent of soil disturbance) of the tillage implement. Some common tillage implements are (in order of decreasing aggressiveness) the moldboard plow, disk, chisel, field cultivator with sweeps, and no-till planter. Researchers from Indiana summarized the effect of various tillage operations on the amount of soil surface covered by wheat residue (as a percentage of the surface covered by residue before that tillage) as follows: reduction of 30–70 percent for disk (one-way, tandem and offset); 25 percent for chisel plow; 20 percent for shovel sweeps on chisel plow; and 10 percent for V-sweep (30 inches or larger). Measurements have been made to determine the amount of oat, corn, and soybean residue remaining on the soil surface after various tillage systems in the upper Midwest. Results showed that the first fall tillage reduced the oat residue cover to 52–72 percent, but a second tillage operation performed several days later did not significantly reduce the percentage of residue cover. The researchers also noted that a small increase in percent cover resulted from some secondary tillage operations if the tillage tools contained sweeps or engaging tools that tended to lift the soil and residue. The effects of tillage on crop residue cover remaining on the surface were similar to those mentioned above for wheat residue.

Research was conducted in Nebraska to evaluate the effects of nine tillage and planting systems on corn residue cover. Investigators found that more residue cover was left on the soil surface (an increase of 33 percent or greater) when one or more primary or secondary tillage operations were eliminated from most tillage-planting systems. They also noted that any tillage-planting system that included either a disk or a chisel-plow operation resulted in surface residue cover of substantially less than 30 percent.

Midwestern researchers presented information on the change in surface residue cover for corn and soybean residue as impacted by both prior tillage and residue type. They found that the amount of soybean (fragile) residue remaining on the soil surface after any given tillage operation was less than the amount of corn (nonfragile) residue for the same tillage, assuming that similar amounts of residue cover were initially present before tillage. Also, the reduction of residue cover by tillage implements was less on

previously tilled soil (secondary tillage) than on previously untilled soil (primary tillage). In fact, some secondary tillage operations (such as field cultivation with sweeps) may bring previously buried residue back to the soil surface (due to the lifting action of the sweep) and thereby slightly increase the percent residue cover. Table 5 summarizes the impact of various tillage implements on residue cover for nonfragile and fragile crops, as published by SCS and EMI (USDA and EMI 1992).

Speed and Depth of Tillage

The effects of the soil-engaging tool (such as chisel tooth, sweep, and disk blade), the speed of operation, and the spacing and depth of tillage on surface residue cover are also important. A study conducted in Illinois evaluated the effects on corn and soybean residue of various soil-engaging tools mounted on a disk chisel and a chisel plow. Results indicated that residue remaining on the soil surface after fall tillage was 47–72 percent for corn stubble and 15–47 percent for soybean stubble. Low and medium crown sweeps (which tend to lift but not invert or throw the soil) maintained the greatest residue cover on the soil surface, compared to the other soil-engaging tools. The amount of surface cover residue left by equipment at low operating speeds (1.5 mi/hr) was significantly greater than the amount left by equipment at higher speeds (3.1–5.6 mi/hr). A research study to evaluate the effects on corn residue cover of various chisel-plow soil-engaging tools showed that a 4-inch twisted shank resulted in greater residue reduction (51 percent reduction) than did a 2-inch straight shank (31 percent reduction). An increase in shank spacing from 12 to 15 inches (less total disturbance) also resulted in less residue reduction, although the difference was minimal (less than 5 percent). Other researchers reported that sweeps reduced oat stubble by 25–35 percent, whereas chisel and disks reduced it by 60–70 percent. In wheat stubble, all these tools resulted in residue reduction of 35–45 percent. One pass of a sweep reduced the irrigated wheat stubble by 20 percent, whereas one disking reduced the residue by 60 percent. Sweep-type implements appear to be much more effective than disk-type tools in leaving residue on the soil surface.

Hamlett and Hoffman (personal communication, 1993) conducted a preliminary evaluation of the effects of primary tillage on corn residue (average yield about 85 bu/acre) in central Pennsylvania. Table 6 presents data for six different tillage operations. About 1 mo after harvest and before tillage, the percent residue cover was 92 and 95 percent for the nonshredded and shredded conditions, respectively. For all tillage operations except the 3-inch twisted-chisel tillage and no-till, the percent residue cover was decreased by about 10 percent if the stalks were shredded. Also, with the exception of the 2-inch-wide straight-shank chisel tillage and the slit tillage (chisel at 30-inch spacing, 2-inch straight shanks), all tillage operations resulted in less than 30

percent surface residue cover. Clearly, primary tillage operations are not advisable if one wants to retain the surface residue cover at levels above 30 percent.

Decomposition of Residue

The decomposition of crop residue is affected by temperature, aeration, pH, and moisture content of the soil; lignin content; C:N ratios; and size and age of residue. The most important factors for consideration are location of residue on or within the soil profile, temperature, moisture, and C:N ratio of the residue.

A simple residue-decay model was developed by Gregory et al. (1985) based on the effects of several important physical, chemical, and microbial elements on residue decomposition. These elements are microorganisms in the soil, temperature of the microorganisms, nitrogen and carbon contents, moisture content of the residue, and surface area of residue. Their residue-decay model was developed to evaluate soil and water conservation-tillage systems. In developing the decay equation, these researchers assumed (1) that residue stems are uniform in length and diameter and (2) that decay over time occurs from the outside to the inside surface of the residue. This model can be used to predict residue decomposition for the Appalachian and Northeast region if the crop and residue factors and the weather conditions are known. Renard et al. (in press) present a reasonable procedure for using this residue-decay equation.

After evaluating this model for soybean, corn, sunflower, and wheat under field conditions, scientists concluded that the model predicted the decomposition-rate values measured in the field. Wheat residue decomposed at a significantly slower rate than did soybean and corn residues. The decomposition rates increased with increasing temperature and moisture content and decreased with lower C:N ratios.

Practical Significance of Type and Amount of Residue Cover

What tillage practices and types of conditions will allow the target levels of surface residue cover to be reached? The most important considerations are the type of previous crop residue, the amount of residue present in the field after harvest, the extent and type of tillage to be performed (including speed and depth), and the weather conditions for the location of interest.

Of these factors, the farm operator has the most impact on residue cover at any point in time by his or her choice of the tillage system(s) used. Table 2 includes an estimate of the residue mass and percent residue cover expected for various crops grown in the Appalachian and Northeast region based

on the average yields for these crops, the commonly used ratios of residue mass to crop yield, and the relationship of residue weight to percent residue cover (Renard et al., in press). This gives an estimate of the surface residue cover that can be expected for the average crops grown. The surface residue covers expected for two yield levels (low and high in table 2) of various crops provide indications of the effects of crop yield and residue type on the expected residue levels. Note that with high yields and no residue removal (harvest), the residue cover in the field will generally be at or above 90 percent for corn, soybeans, and small grains (wheat and oats). This assumes that the residue is distributed fairly evenly across the field as a result of the harvesting operation. (When a large combine is used for harvest without a stalk shredder/spreader or with a less effective spreader/shredder, then the residue will be less evenly distributed and will result in a lower effective percent residue cover.) For low yields, residue cover decreases to around 70–80 percent. Also, as indicated by data in table 6, shredding may slightly increase (by less than 5 percent) the initial residue cover before any tillage activity. However, the shredded residue will be more vulnerable to faster decomposition and incorporation by tillage.

Table 7 presents the decimal fractions to which residue cover is reduced by weathering and by various tillage and planting operations. The products of multiplying these fractions and the assumed initial 0.95 cover provide estimates of surface residue cover on May 1 for various tillage systems on nonfragile and fragile residues for central Pennsylvania. These scenarios exemplify how the percent residue remaining can be calculated and also illustrate the sensitivity of crop residue cover in various tillage, planting, and weathering situations.

When evaluating the *nonfragile crops* (such as nonshredded corn, small grains, and hay), we can see that more than 30 percent residue cover can be attained through several tillage scenarios (all of which generally exclude a moldboard-plowing and a disking operation). The use of no-till provides the greatest residue cover (as expected), followed by chisel-plant and field cultivation-plant systems. However, more than one primary tillage or secondary tillage (or both) operation together will likely result in less than 40 percent surface residue cover. No-till drilling (smooth coulters) of small grains into standing or flat residue will generally result in leaving 60 percent or more of the residue cover. The use of no-till drills with rippled coulters will generally result in 57–65 percent surface cover.

The challenge of maintaining adequate levels of surface cover with *fragile crop residues* is even more pronounced. In none of the scenarios evaluated is it possible to maintain more than 40 percent residue if any type of primary tillage is conducted. Most tillage systems that include more than one primary or secondary tillage operation will result in less

than 30 percent residue cover (the level necessary to be considered a conservation-tillage system). Therefore, for conservation- or reduced-tillage systems to be effective in providing surface cover for soybeans, chopped/shredded residue, and other fragile residues, options must be selected that minimize any tillage operations. As Hoffman (1991) noted for soybeans, it will be very difficult in the Appalachian and Northeast region to maintain greater than 30 percent residue cover in most tillage systems.

Summary

In the Appalachian and Northeast region, a small percentage of total land area is suitable for crops, so it is critical for farm operations and conservation plans to be implemented that will adequately protect the soil surface from excessive runoff and erosion. The amount of residue remaining on the soil surface at any time depends on many factors, including prior crop type and yield, tillage operations, tillage tools, weather conditions, and sequencing of tillage operations. The selection and management of tillage systems that maintain 30 percent residue cover (or more) on the soil surface are becoming critical as farmers adopt conservation plans to try to meet the objectives of the 1985 Food Security Act. As farmers implement these provisions, it will become ever more important for guidance information to be available to help in their selection of appropriate tillage and conservation strategies.

We hope that the information presented here will help in the selection of tillage alternatives to achieve objectives for residue cover and erosion control with various crops. The values provided should be used as general guidelines, with the knowledge that specific equipment and soil-engaging tools used under specific operating conditions and on different soil or crop situations will likely result in somewhat different amounts of residue reduction. However, these estimates are conservative and can be used to assist in the general analysis of various tillage and crop-residue situations. In the Appalachian and Northeast region, a farmer has a fairly broad choice of tillage options for achieving greater than 30 percent residue cover after planting in nonfragile crop residues (such as corn, alfalfa, and small grains). But as residue-cover targets increase to 50 percent or more after planting, the range of tillage options is critically restricted (basically to no-till management). Even more challenging for the farmer is trying to achieve a 30 percent or greater residue cover after planting on fragile residues (such as soybeans, shredded corn and small grains, and vegetables). In these instances, the range of tillage alternatives is reduced substantially; in fact, to maintain greater than 40 percent residue cover, generally a no-till operation must be adopted.

Unfortunately, for many of the row-crop and small-grain acres in the Appalachian and Northeast region, achieving adequate levels of residue cover will be challenging,

especially on lands where corn is harvested for silage, or residue is harvested for bedding, or residue is chopped or shredded as part of the harvesting operation. Where the growing season allows, cover crops such as rye can help to achieve the surface protection desirable for erosion control. Farmers and those professionals who interact and advise farmers need to be aware of the challenges in trying to achieve adequate surface residue levels. The prudent selection of tillage practices for the particular crop and climatic conditions will become ever more important as we strive to sustain our farming enterprise.

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Table 2. Estimates of residue mass and percent residue cover for different yields of selected crops in the Appalachian and Northeast region

Crop	Ratio of residue:yield	Low and high yields (bu/acre)	Residue mass (lb/acre)	Percent residue cover *†
Corn	1.0	75	4,200	75
		125	7,000	91
Oats	2.0	40	2,560	77
		80	5,120	95
Soybeans	1.5	25	2,250	72
		50	4,500	92
Wheat (spring)	1.7	35	3,570	86
		70	7,140	99
Wheat (winter)	1.3	35	2,730	78
		70	5,460	97

* Ratios and residue cover are from U.S. Department of Agriculture 1991.

† Assumes that no residue is harvested from the field.

Table 3. Major crop acreage and yields in the Appalachian and Northeast region

Crop	State group*	Acres	Crop yield† (bu or ton per acre)
Corn grain	Northern	27,308	90.1
	Middle	1,874,280	97.5
	Southern	1,871,583	85.8
Soybeans	Northern	— ‡	—
	Middle	529,099	23.4
	Southern	1,893,216	24.8
Small grains	Northern	40,923	73.2
	Middle	890,527	65.3
	Southern	805,413	57.7
Corn silage	Northern	189,476	16.6
	Middle	998,549	14.3
	Southern	482,482	12.3
Hay	Northern	954,835	2.4
	Middle	4,315,281	2.7
	Southern	3,562,960	1.8
Vegetables	Northern	41,692	—
	Middle	315,087	—
	Southern	73,266	—

* **Northern** includes Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont; **Middle** includes Delaware, New Jersey, New York, and Pennsylvania; **Southern** includes Kentucky, Maryland, Virginia, and West Virginia.

† Data are from 1987 Census of Agriculture (U.S. Department of Commerce 1989).

‡ No data were reported.

Table 4. Classification of fragility of common crops grown in the Appalachian and Northeast region

Nonfragile	Fragile
Alfalfa or legume hay	Dry beans and peas
Corn*	Fall seeded cover crops
Forage silage	Peanuts
Grass hay	Potatoes
Pasture	Soybeans
Small grains (barley, oats, rye, wheat)*	Sweet potatoes
Sorghum	Vegetables

*If these crop residues are chopped at harvest or immediately after harvest, they are considered fragile.

Table 5. Residue cover remaining after tillage, as a percent of surface residue cover present before tillage*

Implement	Percent residue remaining [†]	
	Nonfragile	Fragile [‡]
Primary tillage		
Moldboard plow	0–10	0– 5
Disk plow	10–20	5–15
Disk-subsoiler	30–50	10–20
Chisel plow (sweeps)	70–85	50–60
Chisel plow (straight shanks)	60–80	40–60
Chisel plow (twisted shanks)	50–70	30–40
Coulter chisel (sweeps)	60–80	40–50
Coulter chisel (twisted)	40–60	20–30
Disk chisel (sweeps)	60–70	30–50
Disk chisel (twisted)	30–50	20–30
Offset disk (heavy plowing, >10" spacing)	25–50	10–25
Offset disk (finishing, 7"–9" spacing)	40–70	25–40
Tandem disk (heavy plowing, >10" spacing)	25–50	10–25
Tandem disk (finishing, 7"–9" spacing)	40–70	25–40
One-way disk (12"–16" blades)	40–50	20–40
One-way disk (18"–30" blades)	20–40	10–30
Single gang disk	50–70	40–60
Field cultivator (sweeps, 12"–20")	60–80	55–75
Field cultivator (sweeps or shovels, 6"–12")	35–75	30–70
Rotary tiller (6" depth)	15–35	5–15
Secondary tillage		
Anhydrous applicator	75–85	45–70
Anhydrous applicator with closing disks	60–75	30–50
Subsurface manure injector	60–80	40–60
Light tandem disk after harvest, before tillage	70–80	40–50
Tandem disk (finishing, 7"–9" spacing)	40–70	25–40

(continued)

Table 5—Continued

Implement	Percent residue remaining [†]	
	Nonfragile	Fragile [‡]
Field cultivator (12"–20" sweeps)	80–90	60–75
Field cultivator (6"–12" shovels)	70–80	50–60
Spring tooth harrow	60–80	50–70
Spike tooth harrow	70–90	60–80
Roller harrow (cultipacker)	60–80	50–70
Rotary tiller (3" depth)	40–60	20–40
Row cultivator (30" or wider):		
Single sweep per row	75–90	55–70
Multiple sweeps per row	75–85	55–65
Rolling disk cultivator	45–55	40–50
Ridge till cultivator	20–40	5–25
Rotary hoe	85–90	80–90
<i>Drills and planters</i>		
Conventional planters with:		
Runner openers	85–95	80–90
Staggered double disk openers	90–95	85–95
Double disk openers	85–95	75–85
No-till planters with:		
Smooth coulters	85–95	75–90
Ripple coulters	75–90	70–85
Fluted coulters	65–85	55–80
Strip-till planters with:		
2 or 3 fluted coulters	60–80	50–75
Row-cleaning devices	60–80	50–60
Ridge till planter	40–60	20–40
Semi-deep furrow drill or press drill (7"–12" spacing)	70–90	50–80
Deep furrow drill with >12" spacing	60–80	50–80
Single disk opener drill	85–100	75–85
Double disk opener drill	80–100	60–80
No-till drill in standing stubble with:		
Smooth no-till coulters	85–95	70–85
Ripple or bubble coulters	80–85	65–85
Fluted coulters	75–80	60–80
No-till drill in flat residues with:		
Smooth no-till coulters	65–85	50–70
Ripple or bubble coulters	60–75	45–65
Fluted coulters	55–70	40–60
<i>Climatic effects</i>		
Over winter weathering following summer harvest	70–90	65–85
Over winter weathering following fall harvest	80–95	70–80

*Data are for average conditions adjusted for Appalachian and Northeast region. At shallower depths of tillage and/or slower speeds (than normal), greater amounts of residue will remain on the surface, whereas deeper tillage depths and faster operating speeds will incorporate more residue than normal. Values selected from the specified range should consider these conditions. Source: USDA and EMI 1992.

†Fragile crop residues include soybeans, fall-seeded cover crops, peanuts, and vegetables.

‡If corn stalks or small-grain residue are chopped before tillage or if corn is harvested for silage, consider the residue remaining as "fragile."

Table 6. Preliminary field study of corn residue cover remaining after several primary tillage operations for shredded and nonshredded residue*

Primary tillage operation	Nonshredded residue remaining (% cover)	Shredded residue remaining (% cover)
No-till	92	95
Chisel (2", straight shanks)	62	54
Slit tillage (30" spacing, 2" straight shanks)	41	23
Chisel (3" twisted shanks)	25	23
Disk once (4" depth)	28	18
Disk twice (4" and 3" depths)	23	10

* Data from continuous corn plots in central Pennsylvania

Table 7. Residue reduction and fraction of residue remaining after planting for various tillage and crop-type scenarios in central Pennsylvania* (30% or more residue cover on May 1 is considered a conservation tillage system)

Crop category	Tillage				Planting		Fraction of residue remaining after weathering (decimal fraction)	Estimated† fraction of residue remaining on May 1 (frac.)
	Fraction of residue remaining after primary tillage operations (decimal fraction)		Fraction of residue remaining after secondary tillage operations (decimal fraction)		Fraction of residue remaining after planting operations (decimal fraction)			
Nonfragile	None	1.00	None	1.00	No-till (smooth)	0.85	0.85	0.69
	None	1.00	Anhydrous ammonia injection	0.85	No-till (smooth)	0.80	0.85	0.55
	Disk (6")	0.50	None	1.00	Row planter	0.90	0.85	0.36
	Disk twice (6")	0.35	None	1.00	Row planter	0.90	0.85	0.25
	Chisel (straight, 2")	0.70	None	1.00	Row planter	0.90	0.85	0.51
	Chisel (twisted, 3")	0.60	Disk (3")	0.60	Row planter	0.90	0.85	0.26
	Chisel (straight, 2")	0.70	Disk (3") plus harrow (spike)	0.48	Row planter	0.90	0.85	0.24
	Chisel (straight, 2")	0.70	Disk (3") plus field cult. (sweeps)	0.48	Row planter	0.90	0.85	0.24
	Field cultivator (6"-12")	0.55	None	1.00	Row planter	0.90	0.85	0.40
	Field cultivator (6"-12")	0.55	Disk (3")	0.60	Row planter	0.90	0.85	0.24
	None	1.00	None (flat residue)	1.00	No-till drill (ripple)	0.70	0.85	0.57
	None	1.00	None (standing residue)	1.00	No-till drill (ripple)	0.80	0.85	0.65
Fragile	None	1.00	None	1.00	No-till (smooth)	0.80	0.75	0.57
	None	1.00	Anhydrous ammonia injection	0.60	No-till (smooth)	0.80	0.75	0.34
	Disk (6")	0.35	None	1.00	Row planter	0.85	0.75	0.21
	Chisel (straight)	0.50	None	1.00	Row planter	0.85	0.75	0.30
	Field cultivator (6"-12")	0.50	Disk (3")	0.35	Row planter	0.85	0.75	0.11
	Rotary tiller (6")	0.15	None	1.00	Row planter	0.85	0.75	0.09
	None	1.00	None (flat residue)	1.00	No-till drill	0.60	0.75	0.43

* Assumes that the normal speed and depth of tillage are used and that the overwintering decomposition leaves 85% and 75% of the surface residue for nonfragile and fragile crops, respectively.

† Assumes that 95% of the surface is covered by crop residue immediately after harvest.

11 Weed Management

J.D. Green and Scott Glenn

Over the years, a primary reason for soil tillage in crop production has been the control of weeds. But now that weed control technology has evolved and new herbicides have been developed, the necessity of primary tillage operations for weed control—ranging from moldboard plowing to cultivation—has subsided. However, tillage may be warranted for some weed species (such as perennials with massive underground reproductive structures), particularly in fields with high infestation levels.

Substantial acreage in the most southern states of the Appalachian and Northeast region (Kentucky, West Virginia, Virginia, Maryland, Delaware, and Pennsylvania) is presently managed using reduced-tillage technology—that is, crop residue management. In this region, the predominant reduced-tillage system includes light soil disturbance (such as chisel plowing or disking) or no soil disturbance (no-till). Currently, other reduced-tillage systems, such as ridge till and mulch till, are not commonly practiced in this region.

Regulations within the 1985 and 1990 Farm Bills are designed to control erosion by reducing tillage in crop production, and implementation of those regulations will have the greatest impact on the northern states of this region. The experiences encountered and the weed-control technology developed by the southern states will provide guidance to the region's northern states as they expand their reduced-tillage crop acres.

Managing Weed Problems

When converting from a crop-production system that relies heavily on conventional-tillage methods to a limited tillage system, shifts in the weed species will ensue. In limited tillage systems, either previous crop residues are left on the soil surface, or cover crops are used. There is a greater reliance on herbicides for the control of existing vegetation at or before planting and for season-long weed control. So farm managers must sharpen their weed-management skills to be successful in dealing with their weed problems.

In general, both crop and weed management become increasingly important. To assist in weed-management decisions, one should know the specific weed problems in each field along with other aspects and factors that might influence weed emergence and growth. Characteristics of soil such as texture, organic matter, and pH can influence the performance of herbicides. In addition, one should know the factors that influence the persistence of a herbicide—that is, its potential to carry over and affect the growth of subsequent crops and cover crops.

The proper identification of weeds is an essential component of any successful weed control program. It is even more critical in limited tillage systems, especially no-till, where herbicides are the primary method of weed control. One may need training and a skilled eye to recognize the growth habits of weeds and to properly identify them in their early growth stages. Weeds must be properly identified when they are small, often less than 4 inches high, for effective postemergence herbicide treatment. Thus, field scouting should begin within 2 wk of crop emergence and should continue at weekly intervals for 8–10 wk into the growing season. A field history of previously known weed problems can greatly aid in preparing an overall weed-control strategy at the beginning of the growing season and in identifying potential problem weeds when they emerge. A good method for developing a field history of weed problems is to map the weeds noted in one's field scouting reports.

Low population levels of some weeds do not interfere with the crop's yield, harvestability, or quality. So producers may allow low populations of such weeds to remain in the field throughout the growing season without affecting the crop. On the other hand, problem weeds such as Eastern black nightshade (*Solanum ptycanthum*) and burcucumber (*Sicyos angulatus*) can reduce both crop yield and harvestability. Other weed species such as pigweeds (*Amaranthus* spp.) and common lambsquarters (*Chenopodium album*) are capable of producing several hundred thousand new seeds from a single plant. Therefore, it is often a good strategy to control even low populations of such annual weeds. Light infestations of most perennial weeds should be controlled before they become a serious problem.

In addition to a scouting program and field mapping of weed problems, a good program of integrated weed management should include the use of a variety of crop-management techniques to deal with weed problems. These include cultural practices such as row spacing, seeding rates, and planting dates that maximize the competitiveness of the crop. For example, soybean planted in a narrower row spacing allows quicker development of a crop canopy. This allows the crop to better compete with weeds by reducing the seed germination and growth of weeds.

The rotation of crops can also be an effective tool for managing some problem weeds. Rotation helps to prevent the buildup of some difficult-to-control weeds in continuous-crop production systems. For example, johnsongrass (*Sorghum halepense*) can be difficult to control in corn, but when it is rotated with soybeans, a wider variety of weed-control options is available. Rotation to densely planted crops (that is, forages or small grains) can smother some weeds that compete in row crops. Crop rotation also allows more flexibility in rotating herbicides, which in turn helps prevent the development of herbicide resistance in some weed species.

Less tillage will leave previous crop residue on the soil surface, and that residue will intercept some of the herbicide spray when applied. However, rainfall soon after application generally moves the herbicide off the crop residue into the soil. This reflects the importance of rainfall (instead of mechanical incorporation) in moving a major portion of the herbicide close to the germinating weed seeds. Some herbicides intercepted by the crop residue may be lost from the straw by degradation processes such as photodecomposition or by volatilization. In general, research data have not indicated that the performance of soil-applied herbicides is greatly reduced when crop residue is left on the soil surface.

One noted effect of more residue on the surface is the change in soil characteristics at the soil surface. Generally, under continuous no-till corn production, an increase in soil organic matter occurs from decaying crop residue; and often the soil surface pH becomes more acidic because of annual additions of fertilizers. These two factors can change the effectiveness and the persistence of some herbicides. For example, the triazine herbicides, such as atrazine (AATrex and others) and simazine (Princep and others), tend to be less persistent and may provide less weed control in a no-tillage system than in conventional tillage. This is because of the faster degradation of triazine herbicides under acidic conditions (pH <6.0). Timely applications of lime can help overcome this pH effect. In addition, the buildup of organic matter at the soil surface can “bind” these herbicides and reduce their effectiveness.

The persistence of herbicides used in soybeans can be altered by the presence of previous crop residue. The dissipation of imazaquin (such as Scepter) and imazethapyr (such as Pursuit) has been shown to be more rapid under no-tillage conditions than under reduced and conventional tillage. Faster dissipation of imazaquin may result from photodecomposition when the herbicide is intercepted by previous crop residue. If clomazone (such as Command) is applied to the soil surface (instead of incorporated), the herbicide loss may be more rapid due to volatilization. On the other hand, under no-till conditions, current research indicates that chlorimuron (such as Canopy, Gemini, Lorox Plus, or Preview) may be more persistent. This may be partially due to the interception of chlorimuron by crop residue, which delays its release into the soil profile.

Cover Crops and Winter Annual Weeds

Cover crops have become increasingly important in crop production in order to maintain a 30 percent or greater residue cover on the soil surface. The cover crop used or the previous crop (or both) may determine the weed-control options that are available—especially the control options used to kill the cover crop before planting.

Before planting a cover crop, the first consideration is the herbicides that were applied in the previous crop. Some herbicides may persist in the soil at residual levels that can injure a sensitive cover crop planted in the fall. For example, some legumes and small grains (such as barley, oats, rye, and wheat) can be sensitive to low concentrations of atrazine in the soil. So if atrazine is applied in corn, the ability to plant a cover crop may become limited. Other herbicides containing chlorimuron, clomazone, imazaquin, imazethapyr, or simazine may also reduce the potential of growing a cover crop.

For annual cover crops, the option of using a “burndown” herbicide on the vegetation depends on the cover crop grown. Legume crops such as hairy vetch and crimson clover can be controlled with 2,4-D, dicamba (Banvel, Clarity, and others), or other nonselective herbicides before planting corn. The best control of small grains such as wheat and rye is generally obtained with glyphosate (such as Roundup) or paraquat (such as Gramoxone Extra). Effective control is dependent on the crop growth and environmental conditions at the time of application. In general, a cover crop should be controlled at 2–3 wk before planting, to allow desiccation of the vegetation and to enable planters to cut through the residues and to place seeds at the proper depth and spacing.

Some cover crops have been documented as suppressing the emergence of certain weed species. Natural substances found in plants such as winter rye are released into the soil and are toxic to other plants. Although this response may be variable and limited in the spectrum of weeds controlled, the released compounds may help reduce or delay the emergence of certain weeds. In addition, the heavy mulch created from a desiccated cover crop can contribute to the suppressing effect of the cover. From a practical standpoint, herbicide applications are often still needed when cover crops are used, to obtain the most desirable weed management level. One potential benefit of cover crops is that they compete with the weeds, thereby reducing the populations of some weedy plants. So cover crops may reduce the amount of herbicides used.

Winter annual weeds provide partial ground cover on cropland left idle and undisturbed throughout the winter. In the Appalachian and Northeast region, these weeds include henbit (*Lamium amplexicaule*), deadnettle (*Lamium purpureum*), common chickweed (*Stellaria media*), fleabane (*Erigeron* spp.), and several mustard species. The overall benefits of winter annual weeds that are allowed to grow in a field have not been fully evaluated. The growth and development of these weeds are generally quite variable, depending on the environmental conditions, cropping practices, and herbicides used in the previous crop. One noteworthy benefit of winter annual weeds allowed to grow on idle cropland may be the interception of rainfall by the foliage. This benefit depends on the amount of weed

biomass that is present to intercept raindrop impacts and to retard the surface-water movement. On the other hand, the root development of winter annual weeds may be shallow; in this case, the roots will not bind soil particles as readily as will the roots of a winter cover crop such as wheat and rye. For erosion control, the growth of winter annual weeds on idle cropland is generally better than no vegetative cover.

Shifts in Weed Problems

Weeds become a primary concern when switching from conventional-tillage practices to reduced and no-tillage systems. The idea that weed problems intensify under conservation-tillage systems is a misconception. A more realistic view is that under reduced-tillage conditions, particularly no-till crop production, fields begin to revert to their native “climax” vegetation. When tillage is reduced, populations of annual weeds may decline and a shift often occurs toward the presence of more perennial weeds.

Over time, undisturbed soil reduces the germination of some weed seeds that are deep in the soil. In contrast, soil disturbance through tillage will stimulate the germination of weed seeds by bringing them to the soil surface and by scarification and other processes. If a soil is left undisturbed for several years and is then tilled, a flush of weeds often emerges from the dormant seeds that have been brought to a favorable environment at or near the soil surface.

An occurrence of annual weed species such as maretail (horseweed) (*Conyza canadensis*) and prickly lettuce (*Lactuca serriola*) may be noticed more frequently under limited tillage conditions. These two weed species are considered winter annuals, although they tend to remain throughout the growing season. Perhaps one reason they become established is that their seedlike achenes with tufts of hair are easily spread by wind from one location to another. Thus they can easily invade and become established on fields where primary tillage is not used to destroy the emergence of new plants.

Since maretail and prickly lettuce generally emerge before planting, control measures for them should be initiated before or at planting. When applied before or at the time of planting soybeans, glyphosate (such as Roundup) is an effective nonselective foliar herbicide. Early preplant applications (7–30 days before planting) of 2,4–D Ester alone or tank mixed with another burndown herbicide will also control maretail and prickly lettuce. Another control option is tank mixing a herbicide product containing chlorimuron (Canopy, Gemini, Lorox Plus, Preview, and others) with paraquat (Gramoxone Extra and others) and applying the mixture. These weeds are not common problems in no-till corn production because atrazine (AAtrex) is frequently used for weed control in corn, and

dicamba (Banvel, Clarity, and others) or 2,4–D can be used as foliar applications.

The incidence and severity of perennial weed infestations have increased in some areas of the Appalachian and Northeast region where reduced-tillage crop production is prevalent. Perennial weeds that were seldom found in agronomic crops under conventional-tillage methods may become a greater concern in surface-residue-managed fields. A number of small trees and woody shrubs can also infest no-till fields. This increase in perennial weed problems is due in part to the lack of disturbance of the below-ground reproductive structures (that is, rhizomes, roots, and crowns) when tillage is reduced or eliminated. Herbicides used to control vegetation are not as effective on many of these perennial weed species due to the lack of translocation downward to the roots, rhizomes, and other reproductive structures. This lesser effectiveness is inherent with the chemistry of the herbicide and with the rate used, or it is due to improper timing of herbicide applications to maximize translocation. Many or all of the weeds listed in table 8 can become of greater concern throughout the Appalachian and Northeast region as additional areas of the region expand their reduced-tillage acreage.

Containment of Perennial Weeds

One of the best long-term strategies against perennial weeds is to impede the establishment and population increase of difficult-to-control plants. The grower should scout for the presence of these perennials; as soon as they are detected, steps should be taken to prevent the development of their vegetative reproduction structures and seed production. Methods for controlling low populations of these troublesome weeds may involve intensive herbicide spot treatments or manual removal techniques. Occasionally, timely tillage practices may be necessary to stop entrenchment. This tillage may involve chisel plowing, disking, or even moldboard plowing to destroy or curtail the growth of the vegetative reproductive structures. As discussed in chapter 15 (long-term effects of tillage), many long-term no-tillers are willing to invest heavily in alternatives to such tillage.

The types of herbicides used and the techniques of application must be altered. Soil residual herbicides are generally not effective against many perennial weeds. A systemic foliar herbicide, such as glyphosate, can be used for vegetation burndown and aid in the control of perennial reproductive structures at planting. To suppress perennial weeds like Canada thistle and honeyvine milkweed (which grow actively in the fall), glyphosate, dicamba, or 2,4–D applied alone or as a tank mixture can be used following corn harvest.

Crop rotations can also limit the spread of some perennial weeds. Planting rotational crops (such as small grains)

allows herbicide treatments in a late-summer fallow program. A perennial forage crop can also be an effective rotational crop. The dense growth habit of crops like alfalfa helps to smother some types of perennial weeds. In addition, the frequent mowing of forage crops helps to deplete root reserves of weeds and to limit or eliminate the spread by seed of many weeds.

Resistance of Weeds to Herbicides

A recent concern in weed management is the resistance of weeds to commonly used herbicides. Not all pigweed plants are created alike. And not all common lambsquarters or johnsongrass plants are the same. There is genetic diversity among plants in the same species. Sometimes this diversity is expressed as small differences in the physical appearance of the plants. This diversity can also be expressed as differing responses to herbicides. Genetic diversity within a species that allows biotypes to survive a herbicide treatment that is normally lethal to the species is the basis of herbicide resistance.

Herbicide resistance is commonly associated with the continuous use of a herbicide (or herbicides with the same mode of action) on the same field for several years. These herbicides usually have a single site of action within the plant. As a result, some plants within the species have shown resistance to previously effective herbicides.

Resistance of weeds to herbicides has been reported for a number of herbicide classes. Most attention has been focused on resistance to the triazines, sulfonyleureas, and imidazolinone-type herbicides. In the Appalachian and Northeast region, the incidence of resistance to sulfonyleurea or imidazolinone herbicides is currently not common. However, triazine-resistant weeds have been identified at many locations in this region. In the mid-Atlantic states (Delaware, Maryland, Pennsylvania, and Virginia), triazine-resistant smooth pigweed (*Amaranthus hybridus*) and common lambsquarters (*Chenopodium album*) have become major weed problems. The greatest populations of triazine-resistant weeds are generally in areas where a high percentage of land has been treated with a triazine herbicide and planted in corn for consecutive years with little or no tillage.

Reduced-tillage crop-production systems—especially no-till—require a greater reliance on herbicides for weed control. This puts greater selection pressure on the weed species and increases the probability that herbicide-resistant variants can become established. As a result, herbicide-resistant variants have less competition from susceptible plants of their own species, and therefore become a major or dominant part of that species population.

Nonselective herbicides are often required to "burndown" the existing vegetation before crop emergence. This added

reliance on herbicides may lead to future weed resistance problems. Further, in reduced-tillage crop production, many herbicides that require soil incorporation cannot be used. This decrease in options increases the probability of reliance on one herbicide class, which increases the selection pressures and thus may lead to herbicide resistance.

How can herbicide resistance be avoided?

Rotate herbicides! Do not continuously use the same herbicide (or herbicides with a similar mode of action) each year. Switch frequently to herbicides with alternative modes of action.

Rotate crops! This will provide a greater potential for rotating your herbicides. Some weeds are less competitive in certain crops. Crop rotations can discourage the development of one dominant weed in a field.

Use herbicide treatments with multiple metabolic sites of action! Multiple sites of activity can be obtained by tank mixing and applying effective herbicides that achieve control by attacking different activity sites within the plant.

Prevent the spread of herbicide-resistant weed seeds! Identify resistant weeds. Certainly, those weeds that escape a herbicide treatment can be suspected of herbicide resistance. But not all weed escapes are due to herbicide resistance. Field kits are available in some states to test for triazine resistance. If herbicide resistance is suspected, notify your county agriculture agent.

Control herbicide-resistant weeds! Use alternative herbicides or mechanical methods to prevent seed production in herbicide-resistant weeds.

Do not spread the seeds of herbicide-resistant weeds! Always clean machinery after its use in a field infested with herbicide-resistant weeds. Also, avoid spreading manure or hay that is infested with weed seed.

The Use and Timing of Herbicides

Shifts in weed populations will occur as tillage operations decrease on more of the cropland within the Appalachian and Northeast region. Increases in perennial weeds, herbicide-resistant weeds, and annual weeds that escape burndown herbicide treatments will account for most of these weed shifts. However, changes in the management and timing of herbicide applications will help overcome many of these concerns. One noteworthy benefit of no-till crop-production systems is the ability to operate herbicide application equipment on land sooner following a rainfall event. This benefit provides a wider window of opportunity for applying herbicides on a timely basis during wet seasons.

Preplant soil-incorporated herbicide applications are possible with some crop management systems that leave surface residue, but not with no-till crop production. This narrows the list of herbicides that can be used. Weeds that are more susceptible to herbicides applied preplant incorporated will be less effectively controlled. Herbicides applied to the soil surface are more dependent on rainfall to move the herbicide into the weed seed zone than are herbicides that are mechanically incorporated.

In reduced-tillage systems, herbicides are usually needed to control vegetation before crop emergence. Paraquat (such as Gramoxone Extra) or glyphosate (such as Roundup) are often used to burndown the existing vegetation. In many cases, the green vegetation present among the previous crop residue consists of winter annuals and perennials, along with some emerging summer annual weed species. When planting corn into a perennial grass or grass/legume sod, treatment combinations of atrazine with paraquat or atrazine plus glyphosate provide the best control. Glyphosate applications in the fall are generally more effective in killing perennial weeds and sod crops, especially fields containing orchardgrass, fescue, alfalfa, and/or other forage legumes. To control alfalfa in spring before planting corn, dicamba (such as Banvel or Clarity) should be used.

Where a previous crop residue exists, an alternative to burndown applications at planting is to apply herbicides several days before planting (that is, early preplant). In corn, residual herbicides can be applied as a split application, with the first application made 15–30 days before planting and the second application at planting. Single applications can be successful as much as 15 days ahead of planting. When an early preplant herbicide program is used in corn, a nonselective "burndown" herbicide may not be needed. Early preplant applications have not been as successful with residual herbicide options in soybeans. However, 2,4-D Ester applied 7–30 days before planting soybean can be quite effective against hard-to-control weeds like marehail.

Herbicide formulations are changing to fit the needs of crop production. This whole area of herbicide chemistry promises to continue to evolve as the acreage of reduced tillage increases. Package mixtures of herbicides with more than one active ingredient have become prevalent, partly due to the need for a broad spectrum of weed-control activity. Some specialized herbicide formulations can reduce the "binding" of the herbicide with the plant residue left on the soil surface, such as microencapsulated and water-dispersible formulations. Other formulation changes that may evolve in the future include the development of formulations that reduce the loss of surface-applied herbicides through volatilization.

Greater reliance on postemergence herbicide applications will be required as the acreage of reduced-tillage agriculture increases. Perennial and annual weeds that are not readily controlled by preemergence treatments and weed escapes (due to resistance or environmental conditions not conducive to weed control) must be treated with postemergence herbicides. Many of the new herbicides have postemergence activity in agronomic crops. These postemergence herbicides are being used extensively today in crop-production systems that subscribe to less tillage. In addition, the development of crops resistant to specific herbicides will expand the herbicide options available for weed control in reduced-tillage systems.

The correct identification of weeds and the proper timing of herbicide applications are critical for obtaining optimal weed control. Therefore, in reduced-tillage systems, more management time is required to properly apply herbicides and to make weed-management decisions. Postemergence herbicide applications provide the benefit of allowing the use of an integrated weed-management approach. Thus applications can be made only when needed and on the basis of economic threshold levels.

Summary

Within the southern states of the Appalachian and Northeast region, forms of reduced-tillage crop production (that is, crop residue management) have been common for more than two decades. Much information can be drawn from the weed-related experiences and problems that have developed in these states. This knowledge should help us in predicting and preventing weed-associated problems as the acreage of reduced tillage increases in the northern states of the region. However, weeds and weed-control programs can differ somewhat from state to state. Therefore, local state publications and Extension service personnel should be consulted to determine the most suitable weed-control program for specific problem weeds.

Table 8. Perennial weeds common to the Appalachian and Northeast region in fields where reduced-tillage is practiced*

Bindweed, field	<i>Convolvulus arvensis</i>
Bindweed, hedge	<i>Calystegia sepium</i>
Brambles	<i>Rubus</i> spp.
Canada thistle	<i>Cirsium arvense</i>
Curly dock	<i>Rumex crispus</i>
Dandelion	<i>Taraxacum officinale</i>
Groundcherry	<i>Physalis</i> spp.
Hemp dogbane	<i>Apocynum cannabinum</i>
Horsenettle	<i>Solanum carolinense</i>
Johnsongrass	<i>Sorghum halepense</i>
Milkweed, common	<i>Asclepias syriaca</i>
Milkweed, honeyvine	<i>Ampelamus albidus</i>
Morning-glory, bigroot (or wild sweet potato)	<i>Ipomoea pandurata</i>
Pokeweed, common	<i>Phytolacca americana</i>
Quackgrass	<i>Agropyron repens</i>
Trumpet-creeper	<i>Campsis radicans</i>
Wirestem muhly	<i>Muhlenbergia frondosa</i>

* Weed-management practices are available to control many of these weed species in reduced-tillage systems. Some plants listed can be more difficult to control in reduced tillage than in conventional tillage.

12 Insect and Disease Pest Problems of Field Crops

J.K. Waldron

Crop management systems that reduce tillage and leave all or part of the previous crop's residue on the soil surface are being used to reduce erosion, increase water-use efficiency, and increase soil organic matter. But how will these practices affect insect and disease problems in field crops?

Conservation tillage, in combination with other farm cropping operations, creates a unique ecosystem that can influence the interactions of pests and crops. Research and practical experience indicate that tillage practices (type of equipment, timing in fall or spring, depth and frequency of tillage operation, and weed control) have important effects on many insects and disease organisms. Some insect and disease problems may be reduced in conservation-tillage systems, whereas other problems may be of *greater* concern in conservation tillage than in conventional tillage. Still other insects and disease organisms appear to pose equal risk regardless of the tillage system. Biological control agents can help mediate pest problems, and tillage practices can affect the habitats of those agents. It is difficult to generalize about the impacts of insects and disease under conservation tillage because of their diversity. The effects of tillage practices on pest populations are dynamic, complex, and often poorly understood. The physical factors of soil—such as temperature, moisture, aeration, and compaction—may individually or in combination affect these pests significantly.

From a pest-management perspective, anyone considering the use of conservation tillage can anticipate that this system will provide opportunities to minimize the damage from some pests, will present new challenges for managing other pests, and will require similar management considerations and approaches for still others. Fortunately, the knowledge of pest management that is gained from one tillage system will facilitate the management of the same pests under different tillage systems.

To a large extent, the weather conditions, microenvironment, and certain cultural practices govern what insects and diseases may be present in a field crop, when they may be present, and if they are likely to become economically significant. The major cultural factors that affect the presence and activity of pests are the previous crop(s), date of planting, crop resistance or susceptibility, and degree of crop residue (which is primarily determined by tillage practices).

As with conventional-tillage systems, various crop management practices can be used to help minimize pest problems in conservation-tillage systems. These practices relate to the

rotational sequence, date of planting, and selection of the variety or hybrid. To be able to evaluate the anticipated risk to a crop by a specific pest, a grower will need specific details on the type of reduced-tillage operation and the associated cropping practices.

Although it may not be possible to generalize about the potential impact of tillage practices on insect and disease organisms, it is possible to devise a strategy to help avoid or minimize these problems. The effective management of insects and diseases requires the following: familiarity with the identification and biology of common pests of the crops being considered, an understanding of the factors that contribute to pest activity and economic importance, and ability to thoroughly evaluate appropriate management options. Once this information is known, it can be incorporated into an integrated crop management program that helps to enhance crop production and crop protection in an economical and environmentally sound manner.

For help in anticipating, identifying, and managing the insect and disease problems of field crops in your area, you may obtain the most current and locally adapted information from your local Cooperative Extension personnel and other qualified agricultural professionals.

This chapter provides information on some principles regarding pest activity associated with conservation tillage as well as some potential insect and disease pest problems in corn and soybeans. It also outlines an integrated pest management (IPM) approach for effective insect and disease management under these conditions.

Effects of Conservation Tillage on Field-Crop Insect Pests

Tillage practices alter the populations of insects and other invertebrates (such as slugs) when residue cover provides either a favorable or unfavorable habitat in terms of feeding, oviposition, or overwintering. The success or failure of weed control is also important, because weeds may provide attractive sites for feeding or oviposition.

Tillage and accompanying cropping practices may greatly affect the potential of pests. But research has shown that each insect species must be considered individually; few general conclusions about the risk from insects in conservation-tillage systems are possible at this time. The highest risk of insects to crops grown under conservation tillage appears to be during the first 30–45 days of growth (the seedling stages).

In the Appalachian and Northeast region, several insects may pose a potential risk to crops under conservation tillage as well as to crops under conventional tillage. It is hoped that the information in this chapter will help conservation-

tillage practitioners better anticipate any pest problems. The information is not all-inclusive; a number of other pests may attack a given crop if conditions are favorable. Note also that actual insect problems may be related more to factors like cropping sequence and other cultural practices than to tillage practice.

To ensure that insect problems are kept manageable, it is highly recommended that fields be monitored regularly for pest activity.

Potential Insect Pests in Corn

Many insect pests of corn are commonly found when corn is planted into a grass sod. Corn billbugs (*Calendra* spp.), sod webworms (*Crambus* spp.), white grubs (*Phyllophaga* or *Lachnosterna* spp.), and wireworms (*Melanotus* spp.) may cause stand reductions when corn follows bluegrass, brome, fescue, rye, or wheat. If corn is to be planted into an established grass sod, a planter box application of an insecticide-fungicide seed protectant and a soil insecticide at planting should be considered for the control of wireworms, because no effective rescue treatments are available. A scouting technique of using baits (a buried mixture of wheat and corn seeds) can be used to help detect the presence of wireworms in fields where grasses have been grown for 2 yr or longer. If one or more wireworms per bait station are found, a potential problem exists. Instructions on the construction and use of these pit trap bait stations are generally available through your local Cooperative Extension office or land-grant university field-crop recommendations.

Slugs (shell-less mollusks, not insects) can become a serious pest in conservation-tillage corn production because the crop residue creates a favorable habitat. Continuous corn and first-year corn following sod or grass/legume mixtures are affected equally. Wet, warm spring weather and heavy residue cover favor the buildup of slug populations. Slug damage can be minimized by (1) reduction of the surface residue, particularly in wet areas; (2) proper closure of the seed slot, to prevent slugs (also insects, birds, and mice) from directly feeding on the emerging seedlings; and (3) early-season seeding.

Other early-season problems may be associated with seed germination and emergence. These failures may be the result of poor seed-and-soil contact, cool and wet spring weather, inadequate closing of the seed slot opening made by the planter, the colder soil temperatures associated with heavy mulch covers, and certain soil types or soils with hardpans close to the surface. High organic matter from heavily manured fields and surface or plowed-down crop residues are attractive to seed corn maggots (*Hylemya platura*). This insect may pose a problem to germinating seeds under cool, wet soil conditions, because these condi-

tions slow the seed germination and seedling development. These conditions are also favorable to seedling diseases. In the event of stand-establishment problems, seeds and damaged seedlings should be dug up to determine the cause.

Several Lepidopteran pests, including black cutworms (*Agrotis ipsilon*), armyworms (*Pseudaletia unipuncta*), and stalk borers (*Papaipema nebris*), may become more significant problems under conservation tillage. Successfully predicting the likelihood of damage from these pests requires the consideration of tillage practices, crop rotation, vegetation cover, and density of weed populations. The early detection of these pests is necessary to minimize crop losses. Sometimes these pests are a problem in only limited areas of a field, which may allow targeted localized field treatments.

Black cutworm moths migrate from the southern United States into fields and deposit their eggs on winter annual broadleaf weeds such as peppergrass (*Lepidium* spp.), shepherd's-purse (*Capsella bursa-pastoris*), and common chickweed (*Stellaria media*). Green manure crops are also attractive to black cutworm moths. Weedy fields in early spring are likely targets for egg laying when migrant moth populations are high. Black cutworm infestation is more likely to develop in fields with vegetation cover (including crop residue) than in weed-free fields. Black cutworm infestations are often associated with low wet areas. Injury from black cutworm is generally spotty within the field.

Stalk borer moths deposit eggs on grasses in late summer and early fall. Prime candidates for stalk borer damage are fields planted to corn this season and that contained dense populations of quackgrass (*Elytrigia repens*), giant foxtail (*Setaria faberi*), ragweed (*Ambrosia artemisiifolia*), wirestem muhly (*Muhlenbergia frondosa*), orchardgrass (*Dactylis glomerata*), ryegrass (*Lolium* spp.), or smooth brome (*Bromus inermis*) late last summer. Injury due to stalk borer is closely linked to grass density the previous season, because stalk-borer larvae move from weeds to adjacent corn plants and inflict their damage there.

Armyworm may be the most severe and consistent pest of conservation-tillage corn. Armyworm outbreaks are related to the use of cover crops, tillage practices, and other factors. Armyworm moths migrate from the southern United States in spring. Armyworm moths lay their eggs on grasses. Corn that is planted into a small-grain cover crop (such as rye) in a no-tillage system may be at risk for armyworm defoliation later in the season. Like black cutworm and common stalk borers, young armyworm larvae leave their weed hosts and move to adjacent corn plants.

The European corn borer overwinters as a fully grown larva. Burying or slicing through the crop residue with tillage implements or mowing or shredding the stalks in spring or fall may reduce the survival of overwintering corn-borer

populations in a given field. But the use of a particular tillage practice will not guarantee that an economically significant infestation of corn borers will not develop in a given field in a given year. Factors that interact and ultimately determine the likelihood of an economic infestation developing are the environmental conditions, crop variety, planting date, and intensity of the moth flight. Potential losses from the European corn borer may be minimized by planting corn hybrids that are well adapted to local conditions and that have resistance to stalk lodging. If corn borer has been a problem in the past, one should avoid early maturing hybrids and planting early.

Western and northern corn rootworm beetles (*Diabrotica virgifera virgifera* and *Diabrotica barberi*, respectively) are two of the most important insect pests of corn in the Northeast region. Corn rootworm may be a problem in second or later years of continuous corn and only very rarely are a problem in first-year corn. Corn rootworm eggs are deposited in the soil in late summer and serve as the overwintering stage. Eggs hatch the following year in May to early June (under New York conditions), and the larvae feed on corn roots. Adult corn rootworm beetles can be easily found in corn fields during the time of tasselling through pollination. The best management practice for corn rootworm is simply to rotate the corn with another crop. This rotation effectively breaks the life cycle, which reduces the population of the western corn rootworm and eliminates the majority of northern corn rootworm. Research to date has not shown a clear effect of tillage practices on corn-rootworm populations.

Potential Insect Pests in Soybean

Compared to research on corn insects, less research has focused on the impact of various cultural practices on soybean insect pests. Seedcorn maggot may cause emergence problems in fields with high levels of organic matter. Most insects considered to be economic pests of soybean are defoliators or pod feeders. These insects are often highly mobile and readily move from field to field. Tillage practices are generally thought to have little effect on pest damage caused by soybean defoliators. It is anticipated that differences in weed density and species composition are major factors that affect insect communities that inhabit foliage.

Research from Ohio indicates that Japanese beetles (*Popillia japonica*) may be most numerous in reduced-tillage soybeans after corn. Additional research from Ohio indicates a similar trend for Japanese beetles and bean leaf beetles (*Cerotoma trifurcata*) in soybeans after rye grass.

Beneficial Insect Populations

Little information is available about the effects of conservation-tillage practices on the populations of beneficial insects. There is evidence (although not yet conclusive) that reduced-tillage crops may support a larger and more diverse arthropod community than do conventional-till crops. One factor is often cited as being responsible for the lower numbers of many pest species in conservation-tillage fields—namely, the greater density and diversity of predatory fauna associated with greater residue cover and weed densities. Although no direct relationship has been established, evidence suggests an important role of predators in conservation-tillage systems. Studies have shown that predaceous members of the Carabidae (ground beetles) and Staphylinidae (rove beetles) families and also spiders frequently occur in higher numbers in no-tillage systems than in conventional-tillage systems. Because many invertebrate species that feed on living and dead plants also show this trend, researchers have suggested that the activity of arthropod predators may be greater in the no-tillage systems. But the increased moisture, reduced temperature, and reduced lighting that occur in the mulch residues of conservation-tillage systems also favor the development of insect-disease epidemics caused by fungi, viruses, and bacteria. It has been observed that the populations of nematodes that feed on insects are higher under conservation-tillage systems than under plow tillage.

Effects of Conservation Tillage on Field-Crop Diseases

Conservation-tillage practices may affect disease development directly or indirectly by affecting the surface residue or soil physical factors and ultimately either the pathogen or host. These pathogens include the fungi, bacteria, and viruses that attack plants and can cause disease. The development of plant disease is determined by the presence of a disease organism, a susceptible host, and a favorable environment. Infection and disease development are very dependent on weather conditions and on the susceptibility of the crop to the particular disease organism. Disease development occurs only when these components occur together for a critical period of time. The interactions that lead to disease development are complex and vary significantly with the disease organism and host.

Crop disease in conservation-tillage systems can be a concern because many plant pathogens can persist through the winter, spring, and early summer on infected plant parts. The relatively slow decomposition of surface residues provides readily available nutrients over a long period of time for many plant disease organisms (primarily pathogenic fungi and some pathogenic bacteria) to germinate, grow, reproduce, and colonize the crop hosts. In these ways, slowly decomposing surface residues may effectively harbor disease organisms that contribute to outbreaks of disease.

The relatively rapid decomposition of residues incorporated into the soil with conventional-tillage systems will reduce the relative number of many fungal and bacterial pathogens associated with residues. Also, the decomposition of residues incorporated in soil may stimulate the growth of microorganisms that are detrimental to pathogens associated with residue and thus reduce the incidence of soilborne disease. Residue in soil may, however, favor the development of certain soilborne diseases by stimulating the growth and reproduction of soil-inhabiting disease organisms and by producing materials that may be toxic to roots.

Conservation-tillage systems, in contrast to conventional-tillage systems, are characterized by slowly decomposing surface residue, which generally retains a higher soil moisture content and maintains a lower soil temperature during the growing season. Later in the season, these moist and cooler conditions may create a physical environment in the soil that promotes the development of a vigorous plant; this plant would be less affected by crop stresses and more resistant to pathogens, particularly to soilborne pathogens.

So when one considers the effects of tillage on disease incidence, one must consider the complex relationship between the host, the disease organism, and the resulting environmental conditions. Thus, as with insect pests, it is difficult to generalize the overall impact of conservation tillage on the incidence of diseases.

Experience has shown that some plant diseases pose a greater potential risk than others to crops under conservation tillage. To increase the chances of a healthy crop, proper agronomic practices should be used that enhance the stand establishment and crop growth, such as the use of disease-resistant varieties or hybrids, proper seed-bed preparation, proper planting date, and proper soil fertility and pH. It is highly recommended that fields be regularly monitored for the presence of diseases and that the diseases be properly identified. It should be remembered that the mere presence of a disease organism does not imply that severe disease will develop. Disease will develop only when a disease organism and a susceptible host are present in a suitable environment for a critical period of time. If any one of these components is missing, significant disease will not occur.

It is hoped that the following text will help conservation-tillage practitioners better anticipate these disease problems. This information is not all-inclusive; a number of other diseases may attack a given crop if conditions are favorable. Note also that actual disease incidence may not be directly related to tillage choice but may be related to factors like cropping sequence and other cultural practices.

Early-Season Diseases and Soilborne Diseases

A good correlation exists between early-season crop diseases and the conservation-tillage practice. Surface residues may create a soil environment that is favorable for disease development and unfavorable for plant growth early in the growing season.

Disease problems may occur when seeds are planted into soils that stay cool and wet for extended periods in spring. These early-season environmental conditions can be exacerbated by heavy amounts of crop residue left on the soil surface in conservation tillage. These conditions can retard seed germination and seedling development, which in turn may lead to seed decay, seedling damping-off, and root rots caused by soilborne pathogens such as *Pythium*, *Phytophthora*, and *Rhizoctonia*. This effect can be partly overcome by redistributing the residues away from the emerging seedlings, as is done with the use of row-cleaning devices. As a reasonable precaution, it is recommended that only quality seed that has been treated with a fungicide seed protectant should be sown. As with conventional-tillage systems, one should consider the need to protect from seed corn maggot and wireworm when crops are planted into sods.

Many microorganisms that attack the roots, root-crown area, stems, and seedlings are soilborne and are well equipped to survive in the soil. Soilborne disease organisms have resistant life stages that allow them to survive after the host residue has decomposed. One might expect these microorganisms to be less influenced by tillage. The relationship of these soilborne microorganisms to conservation tillage is related to the effect of surface residues on the soil and crop environment. Disease development may be influenced *directly* by affecting the pathogens or *indirectly* by affecting the pathogen survival or host susceptibility. Research has shown that a number of soilborne diseases decrease with deep tillage. For example, bare patch of wheat caused by *Rhizoctonia solani* and Cephalosporium stripe of wheat caused by *Cephalosporium graminearum* can be reduced by moldboard plowing. On the other hand, no-tillage can reduce common root rot of wheat caused by *Bipolaris sorokiniana*. Nematode populations are influenced by tillage practices. The number of cyst nematode (*Heterodera glycines*) eggs on soybean and the population of *Pratylenchus hexincisus* in corn roots were greater following conventional tillage than following no-tillage.

There is some evidence that corn residue can emit water-soluble toxins that percolate into the root zone with rainwater and can be taken up by seedlings. These toxins cause stunting of root growth, stunting of top growth, and yellowing of leaves. This is most apparent with no-till corn. Note that poor crop growth may have many causes, such as poor fertility or pH, diseases, herbicide injury, soil compaction,

and moisture stress. Proper diagnosis of the problem is critical to effective management.

Foliar Diseases

The adoption of conservation tillage will likely increase a number of foliar diseases. This is due to a positive relationship between the host residues and the survival of many foliar pathogens. Many plant pathogens that attack aboveground plant parts are poor competitors and normally do not survive in residue buried in the soil for more than a few months (except when temperatures are low or when the soil is very dry).

In conventional tillage, residue is buried in the soil, where it is generally kept continually moist. Under these conditions, a reduced pathogen population is available to cause disease; this reduction results from the antagonistic activities of other soil microorganisms that colonize the decaying residue. The antagonistic microorganisms destroy or suppress the pathogens and decompose the residue, thereby depriving the pathogens of protection and a nutrient source. For example, deep tillage that buries crop residue has been shown to reduce southern corn leaf blight and gray leafspot of corn, stem canker of soybean, and glume blotch of wheat.

In contrast, when residue remains on the soil surface (as in conservation-tillage systems), the rate of decomposition is slower, and cool, wet spring weather is likely to induce multiplication of the pathogen on the residue. Because the pathogen population is present and near the site of infection at planting, the plants may become infected much earlier than if the disease were induced by airborne inoculum that overwintered elsewhere and depended on air currents for dispersal. If favorable environmental conditions persist, many of these diseases will continue to move from the lower plant regions up through the plant canopy.

A number of foliar diseases may be affected by the amount of infected crop residues on the soil surface. In the Appalachian and Northeast region, the more common diseases affected by this practice are as follows:

In corn: anthracnose (*Colletotrichum graminicola*), eyespot (*Kabatiella zeae*), gray leaf spot (*Cercospora zeae-maydis*), northern leaf spot (*Bipolaris zeicola*), northern leaf blight (*Exserohilum turcicum*), southern leaf blight (*Bipolaris maydis*), and Gibberella stalk rot (*Gibberella zeae*)

In wheat: tan spot (*Pyrenophora tritici-repentis*), Septoria leaf, and glume blotch (*Septoria* spp.)

In soybeans: pod and stem blight (*Diaporthe phaseolorum* var. *sojae*), bacterial blight (*Pseudomonas syringae* pv. *glycinea*), and brown spot (*Septoria glycines*)

Late-Season Diseases

The association between late-season diseases and conservation-tillage practices is less clear than that for early-season diseases. For example, in New York state, studies with yellow leaf blight showed more disease under conservation tillage than under conventional tillage early in the growing season, but equivalent levels of disease were found later in the same season.

Later in the growing season, conservation tillage may provide an environment that helps to minimize crop stress by decreasing the evaporation and protecting the soil moisture. These environmental conditions are generally favorable for crop growth and development, and they can help minimize stress diseases such as stalk rot of corn. Stalk rot—caused by several different genera of soil fungi—is considered a stress disease because it is accentuated when plants are stressed during grain filling by drought, hail damage, corn borer injury, extended cloudiness, and foliar diseases.

Other Diseases

The correlations between diseases and conservation-tillage systems are stronger for fungal and bacterial diseases and weaker for viral and nematode problems. Many viral diseases are greatly affected by cropping history, alternate hosts, or disease carriers such as aphids and leafhoppers. These factors may also be greatly affected by tillage and other cultural practices. Tillage operations appear to be less influential than cropping sequence on the populations of plant parasitic nematodes.

Cultural Practices: Role of Rotations

Cultural practices can greatly affect the populations of pests. For this reason, it is important to use a variety of cropping practices in an integrated approach that helps to effectively and economically manage potential pest problems.

Crop rotation is a cultural practice that is used routinely as a method of increasing yields by maintaining the soil fertility and soil structure and by disrupting the life cycle of insects, weeds, and plant pathogens.

Although there are still many unanswered questions about the interactions of conservation-tillage systems and rotations as related to pest populations, it is likely that crop rotations will help minimize the impacts of a number of key pests—particularly foliar diseases, soilborne insects, and (to a certain extent) weeds. These impacts are expected to parallel those observed when rotations are conducted in conventional-tillage systems.

Knowledge of the biology—including the preferred hosts of locally important pests—can help guide the selection of appropriate rotation systems. Weed management is another important concern because weeds are attractive to certain insect pests and disease organisms and may serve as alternate hosts for them.

Rotations are particularly successful in reducing the impact of insects that have a limited host range or limited mobility, such as insects that live in the soil. They can be controlled by rotating crops to a nonhost. For corn, these crops are typically a legume or possibly a small grain. It has been mentioned that corn rootworm populations are not clearly affected by conservation tillage, but they are effectively reduced by crop rotation.

One of the greatest benefits of rotation is its ability to reduce the incidence of many plant diseases that are perpetuated by contaminated crop residue. Just as rotations are the most successful means of minimizing the impact of insects with a limited host range, rotations are also effective against many of the following soil plant pathogens: those with limited host ranges, those that infect their hosts through crop residues left in or on the soil, and those that form various survival propagules in the soil.

Rotations can effectively reduce the potential impact of a number of corn diseases, including southern and northern leaf blights, eyespot, gray leaf spot, and anthracnose. The chemical-control options for many field crop diseases are limited, so crop rotation and the use of disease-resistant varieties—combined with sound agronomic practices—are the most economical and effective control measures for many field crop diseases.

Integrated Pest Management (IPM) for Field Crops in Conservation Tillage

The efficient management of insects and diseases involves the use of sound agronomic practices. Included are close attention to factors like site selection, seed-bed preparation, timing of planting, selection of locally adapted pest-resistant or pest-tolerant varieties or hybrids, soil fertility, and soil pH. Information on the best management practices that are appropriate for crops in your locality is available through cooperative extension personnel and other qualified agricultural professionals. In addition to these factors, integrated pest management (IPM) techniques can be used to better meet the challenges of pest control.

IPM is a management philosophy in which short-term and long-term crop-production strategies are used to minimize losses from pests and also provide optimal net profit to the producer and minimal disruption to the environment.

Among the factors considered in the IPM approach are

- What pests (insects, diseases, and weeds) are present or expected?
- When and at what level of infestation do the pests cause economic losses?
- What different methods can be used to control or avoid the pests?
- When should these control strategies be used?

To optimize the benefits that can be achieved through the use of IPM, become acquainted with the insect and disease problems that commonly occur on field crops in your area. Most states have IPM information for major commodities that is available through their cooperative extension programs or land-grant universities. This information describes the key pests that occur locally, when the pests appear during the season, how to effectively monitor pest problems, the crop stages that are most susceptible to the damage, the action threshold for treating pest problems, recommended alternatives for effective pest control, and how to obtain additional information tailored to meet your local needs or concerns.

It is recommended that you walk your fields regularly during the growing season to detect potential problems early. These field visits should provide information that is representative of the whole field. It is important to walk into the field at least 50–100 ft to avoid border effects. Vary the point of entry and of exit on each visit. Once in the field, walk in an M-shaped or W-shaped zigzag pattern across the field, to increase the probability of finding isolated problems. These field visits must coincide with the times of potential activity of insects, diseases, and weeds. It is appropriate to walk your field once a week, particularly within the first 30–45 days of crop growth, or at critical crop growth stages, such as emergence, bloom, grain, and pod fill. These critical periods will vary with the crop and the pest complex. Keep a record of observations during your field visits for future reference. Record any information on pests, crop growth, crop status, and other important cropping activities.

Six Steps to Successful Pest Management

A six-step approach to IPM can be used to successfully manage pest problems. This approach helps provide the information necessary to detect and effectively manage pest problems before they cause economic losses. This information also helps to avoid unnecessary actions and thereby optimize your economic returns and minimize risk to the environment. The six steps of IPM involve identification, sampling, analysis, management alternatives, implementation, and evaluation. This approach provides individualized crop and pest information that enables you to make management decisions based on real crop needs.

Conscientious use of these principles in the order presented will maximize the advantages of the IPM approach. The correct completion of each step *in the order presented* is vital to the overall impact of IPM, because each step builds on the information and results of the previous step.

Six Steps to Using Integrated Pest Management (IPM)

1. Identification

Correct identification is the cornerstone of successful integrated pest management. Misidentification leads to *mis*-management. If an unknown “*pest*” is frequently seen or is suspected of causing a problem, it should be correctly identified. If in doubt, collect a representative sample and send it to an appropriate diagnostic laboratory. Most land-grant universities have diagnostic laboratories for identifying crop insects, diseases, and weeds.

2. Sampling

Determine if the pest is common throughout the field, or is observed only in isolated areas, or is associated with a particular field pattern. In what stage of development are the observed pests? In what stage of development is the crop? Effective IPM sampling methods have been developed for many pests—particularly insects—to obtain a representative assessment of pest infestations. Consult your local cooperative extension personnel or other agricultural professionals for information on IPM monitoring techniques or reference materials.

In conservation-tillage systems, pay particular attention to weedy patches within and next to the field for indications of insect problems. In fields with high surface residue, check for slugs in young corn, monitor foliar diseases on lower leaves of crops, and follow disease development through the season.

Remember that the goal of crop monitoring is to gain information on the overall field condition and pest status.

3. Analysis

Healthy crops tolerate a modest amount of pest damage before the net profitability is affected. Before this level of damage is reached, the costs of control exceed the actual crop losses. This concept of *economic threshold* is basic to the use of IPM. A grower needs to consider the pest and the crop stage of development. Threshold guidelines for evaluating the potential impact of specific pests are available in field-crop and IPM publications from land-grant universities. Note that localized treatments rather than whole-field treatments may be suitable for some pests like black cutworm and weed species. For many field-crop

diseases (other than small-grain cereals), rescue chemical treatments are not available. A correct diagnosis of the disease is necessary to permit the future selection of disease-resistant varieties or hybrids and also the use of other disease-management practices.

4. Management Alternatives

A variety of cultural, biological, and chemical management alternatives are available to minimize the impacts of pests (insect, disease, and weed). The early detection of pest problems provides increased opportunities for using the least toxic approaches to pest management. In choosing the most appropriate option, one should consider the short-term and long-term benefits and implications of the proposed action. If pesticide options are to be used, be sure that the materials are used in compliance with state and federal laws. In many states, local cooperative extension and soil conservation service offices can help determine the potential surface runoff and leaching of pesticides on specific soils. This is another tool that can be used to help evaluate and enhance environmental protection aspects of field-by-field pesticide-use decisions.

5. Implementation

Once a management alternative has been chosen, it must be carried out in a complete and timely manner to obtain the maximum benefit.

The documentation of pest-management activities is highly recommended, to provide a record of the actions taken and to help evaluate their effectiveness, including the impact on the net profitability of crop production.

If a pesticide application is to be made, the application equipment must be calibrated and adjusted to ensure proper coverage and rate of application. Information on the pesticide use should be recorded when it is applied. Be sure to comply with state and federal pesticide-use regulations. Items to be recorded are the name of the pesticide being used, the target pest(s), rate of application, total quantity used, method of application, place and date of treatment, and any pertinent comments such as weather conditions, crop-growth stage, efficacy, and name of person applying the pesticide.

6. Evaluation

Documenting the process of pest-control decisions will provide important feedback for assessing the effectiveness and impact of actions taken and for improving any future management decisions. This information should be collected when making field visits and then kept for future reference. Information such as weed control, the particular insect and

disease pests, and general crop performance is invaluable for developing improved management strategies. Later you can determine how well the pest-management strategies worked. In this way, you can identify both major successes and areas that require improvement in subsequent years.

Summary

Conservation-tillage practices have many positive attributes of crop production and soil protection. Field conditions created by conservation tillage may dramatically affect some crop insects and diseases but not affect others. The amount of crop residue and other associated cropping practices can *directly* affect the survival of insects and crop pathogens through the field's attractiveness to insect pests, or *indirectly* through the impacts on localized environment (such as soil temperature, soil moisture, and soil aeration) that affect pest survival or crop vigor. The impact of conservation-tillage systems on insect and disease problems of crops is complex. But current information indicates that many of the pest-management strategies developed for specific pests in conventional-tillage systems can be readily applied to manage the same pests in conservation-tillage systems.

The use of an IPM approach increases the efficiency and effectiveness of pest-management decisions. To best capitalize on the IPM approach, visit your fields frequently (once a week if possible) to monitor the crop condition and pest activity. Conservation-tillage field conditions that require particular attention are continuous cropping situations, especially for foliar diseases; fields with poor weed control, particularly for insect pests; and cropping factors that affect crop vigor or may contribute to crop stress. For further information on possible pests in conservation-tillage systems, contact your local cooperative extension office.

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13 Erosion Control in Crops That Produce Sparse Residue

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In cooperation with soil conservationists and agricultural researchers across the Appalachian and Northeast region

Use of Cover Crops

Cover crops are beneficial because they reduce soil erosion, improve soil physical properties, add and recycle nutrients, suppress weeds, and disrupt the life cycles of insects and diseases. Since the purpose of this manual is to provide information that will help Appalachian and Northeast growers increase soil surface cover on highly erodible soils, our focus is on cover crops that will complement crop residues in erosion control, specifically crops that produce little residue.

Winter Cover Crops

The growth of winter cover crops may be one of the best management strategies for enhancing agricultural sustainability. Cover crops not only prevent erosion but also absorb most of the free nitrate in the root zone, thus reducing the amount of nitrates moving into ground and surface waters. In poorly drained soils, the winter cover crops remove water, allowing the seeding of summer crops without soil compaction. Conversely, in droughty or well-drained soils, the primary potential disadvantage of cover crops is their consumption of water that is necessary for the spring-planted crop. But this water use can be monitored, and the cover crop can be killed or harvested for forage at a water level that is appropriate for summer planting. In areas where winter precipitation exceeds that needed to recharge the soil profiles, a winter cover crop will benefit those growers who are willing to manage it carefully.

Temporary Vegetative Cover

It is advisable to plant temporary vegetative cover on soils that are exposed for periods of 1–12 mo. This serves as a protective measure to control the erosion from wind, rain, runoff, and snowmelt and also controls sedimentation. For these reasons, it is desirable to use cover crops on agricultural fields where bare soil is exposed. A cover crop is generally needed for erosion control in corn harvested for silage, in soybeans, tobacco, potatoes, other vegetables, and other low-residue-producing crops planted on erodible land. Cover crops may be planted to provide ground cover in summer (for instance, following early vegetables), fall, or winter. For seasonal cover crops, annual grasses are

commonly used alone and give satisfactory results at a reasonable cost. Selection of species will vary with the season. In the Appalachian and Northeast region, land in corn silage production accounts for the largest share, by far, of acreage requiring cover crops. Silage fields are left bare at a time when they are most vulnerable to erosion from fall and winter precipitation. A fall-seeded cover crop can provide substantial cover, thus reducing the soil losses due to erosion.

Early seeding, rapid and uniform germination, and vigorous growth are necessary characteristics of a cover crop being selected for erosion control. The seeding of cover crops as early as possible will usually result in satisfactory cover. Cover crops can be established either by seeding immediately after the main crop harvest or, for late harvests, by interseeding into the standing crop at the last cultivation (corn 6–24 inches tall) or aerially in tasseling corn. For fall seedings, it is vital for seeding to be no later than the recommended period for the species, so that sufficient growth can occur before the winter dormant season begins.

Methods of Seeding

Obtaining a uniform cover-crop stand depends on the method of seeding. Drilling the seed, which gives good contact of the seed and soil, results in the most uniform stands. Stands are less uniform when the seed is broadcast by hand (with rotary or centrifugal-type seeders) or by airplane. These last methods require higher seeding rates to compensate for the poorer seed coverage. Specific methods of seeding are as follows:

1. Interseed into corn at last cultivation. This can be combined with either cultivation or fertilizer sidedressing operations.
2. Drill immediately after silage harvests with a no-till drill or conventional grain drill with packer wheels.
3. Use a tractor-mounted rotary seeder (either power takeoff or engine fan operated).
4. Broadcast and lightly disk 1/2 to 1 inch immediately after silage harvest. Do not broadcast without disking after harvest. Rolling or packing will improve both stand and uniformity. This is particularly important where the growing season is short, as in northern New England and New York.
5. Aerially seed into standing corn in late August. Rapid germination of seed helps to overcome weaknesses of seedings done later in the planting period. When later seedings are necessary, select a cover crop that will germinate rapidly to help assure a successful stand. Annuals generally germinate more rapidly than perennials, and grasses generally germinate faster than legumes. The

annuals that establish most readily are, in order of their speed of emergence, annual ryegrass, spring oats, millet, winter wheat and rye, and sudangrass.

Establishing cover crops in low-residue-producing crops is usually best accomplished with winter (cereal) rye. In all reporting states, from Maine to Kentucky, rye is the most widely used cover-crop species. Rye grows under a wide range of conditions, is cold tolerant, germinates rapidly, and has excellent seedling vigor. These traits make rye useful and adaptable to many geographic and climatic conditions.

As discussed in chapter 4 (Interaction of Surface Residue With Soil and Climate), temperature is the most important factor affecting the time required for a crop to mature. A heat-unit or degree-day system has been devised to help growers plan or schedule the planting of several crops. Heat units are determined by subtracting a base temperature (40 °F for rye) from the daily average. The number of growing degree days (GDD) required for the maturation of various cover crops has been determined. Summing the accumulated heat units throughout the growing season will enable a grower to predict crop maturity. Rye requires a minimum of 260 GDD (at base 40 °F) just to become established, and a minimum of 350 GDD for effective growth and cover into winter. Final planting dates for rye (using 2 bu/acre) range from September 25 in Corinna, ME, to October 15 in the Coastal Plain region of Maryland. In New York and states to the north, this date is generally about October 1. Refer to table 9 to determine the approximate GDD for your region and location.

The rye variety ‘Aroostook’ was released in 1981, following its development in New York and particularly in northern Maine (Presque Isle). ‘Aroostook’ rye is commonly recommended in many of the northeastern states. It germinates in soils as cool as 50 °F and will make vigorous growth when sown as late as September 30 in northern Maine; this makes it particularly well-suited to the northern states in the Appalachian and Northeast region, or to later plantings in the southern portion of the region. But it does not perform better than other rye varieties when grown in the sandy soils of the mid-Atlantic coastal region.

A list of the common and Latin names of most of the cover crops used in the Appalachian and Northeast region is provided in table 10.

Recommendations for Connecticut and Rhode Island

In Connecticut and Rhode Island, cover crops are predominantly required for silage corn. Planting dates for rye (variety ‘Aroostook’) are September 1–15 with an extension to October 1. Optimum growing conditions are obtained when planted by September 15 for higher elevations and

September 30 for lower elevations. Table 11 gives seeding rates and planting dates for other choices of cover crops.

Seeding Rates

The seeding rates for rye are 2 bu/acre before September 15, 3 bu/acre from September 15 to 30, and 4 bu/acre at all later dates. Aerial seeding will require increasing the seeding rate by 50 percent; this seeding should take place within 30 days of harvest to prevent poor stand vigor and damage to the cover crop during harvesting.

Comments

Living mulches (such as crownvetch and flatpea) planted into silage corn are very complex systems to manage and are not widely used. Interseeding with rye is more effective than interseeding with other living mulches.

Recommendations for Delaware

The establishment of a cover crop for no-till corn and soybean production and for ridge tillage has been extensively researched at the University of Delaware. More complete publications concerning these programs may be obtained from the University of Delaware (Plant and Soil Sciences Department, Newark, DE 19717–1303).

Winter rye, barley, and wheat can be used as mulch covers for no-tillage corn and soybeans. Rye is the most desirable because it is the easiest to regulate chemically in the spring. If a small grain is selected for a cover crop, then rye is the crop of choice, for economic reasons. None of the small grains should be allowed to grow beyond the boot stage before regulation. Generally 30 inches tall is adequate growth for rye to provide a good mulch layer. If allowed to get too tall or too mature, the mulch layer takes longer to form and valuable water can be removed from the soil.

Nitrogen-producing winter annuals (hairy vetch, Austrian winter pea, crimson clover, and red clover) will provide excellent mulch cover if planted early in the fall and allowed to grow later in spring. Also, these covers add 50–100 lb/acre of nitrogen. These covers are especially suitable when grown in rotation with silage corn. Table 12 gives seeding rates and planting dates for these legumes in Delaware.

Reshaping the ridges in the fall following harvest of ridge-till corn will prepare the ridges for cover-crop planting. Many cover crops can be used in this planting system, including grasses and legumes. A mixture of annual ryegrass and hairy vetch has proven to be particularly effective in studies conducted at the University of Delaware. This species combination provides the strong, soil-binding

root system of ryegrass plus the nitrogen-fixing potential of vetch. Broadcasting with ground or aerial equipment on freshly prepared ridges provides good seed-soil contact without additional soil mixing. Experience has shown that following ridge reshaping, broadcast seed will bounce off the tops of ridges and slide toward the “valleys” between them. These moist, protected areas are ideal for seed germination. The seed is concentrated as it migrates down the ridge slopes, resulting in good stands at reduced seeding rates. A mixture of 10 lb of annual ryegrass and 10 lb of hairy vetch provides a very effective soil-stabilizing cover and a significant nitrogen contribution.

Recommendations for Kentucky

Comments

In no-till vegetable-production research at the University of Kentucky, it has been shown that winter rye cover crops have been successfully used when growing processing tomatoes (transplanted) and direct-seeded cucumbers, beans, and corn. Winter rye suppresses weeds and is compatible with vegetable establishment. Winter wheat is also generally successful. Oats, barley, and vetch are more difficult to establish, are less vigorous, and are less weed suppressive. For summer-planted crops, the sorghums are often an excellent choice for a green manure crop or cover crop. They also offer promise in fall-cropping systems for cole crops. If cover crops are used in vegetable production systems, chemical regulation of the cover crops is more effective than mowing. Glyphosate (such as Roundup) is recommended for regulation, followed by postemergence selective herbicides to control annual grass weeds. In no-till systems, early sidedress applications of fertilizer are often required to compensate for the initial nitrogen tieup that occurs in the early stages of cover-crop-residue decomposition.

Table 13 gives seeding rates for various choices of cover crops for silage corn in Kentucky.

Recommendations for Maine

Seeding Dates

The latest recommended planting dates for winter rye in Maine are from September 15 to October 20. Planting after October 5 will require more than 112 lb/acre (2 bu) and may not be cost effective. Winter rye is recommended for seeding immediately following potato harvest. However, in silage corn, interseeding is recommended because aerial seeding is not cost effective. Interseeding is done when the corn is 6–24 inches tall in the same operation as the last cultivation. This ensures good seed coverage.

Table 14 gives seeding rates and planting dates for other choices of cover crops in Maine.

Comments

Hairy vetch has been shown to be a valuable winter cover crop for improving soil nitrogen fertility, limiting erosion, and suppressing weed growth in areas to the south of central Maine. Research conducted at the University of Maine has shown that hairy vetch establishment and fall biomass production were greatly favored by planting in mid-August rather than early September. Companion cereal crops decreased the weed growth but also depressed the vetch growth. With a mid-August seeding date, vetch growth was greater on a fine sandy loam than on a silt loam soil. However, following several years' experiments, it was determined that hairy vetch is not useful as a winter cover crop in central Maine. It does not overwinter successfully, and it costs much more than other crops such as oats. So hairy vetch is not the best choice.

Recommendations for Maryland

Establishing cover crops in Maryland after silage corn, soybeans, tobacco, potatoes, and other vegetables is usually best accomplished with grain (winter) rye. Hairy vetch performs well in all areas of the state. Bigflower vetch, Austrian winter peas, and crimson clover are also adapted to the state's climate. When legumes and grass cover crops are mixed, Austrian winter peas and crimson clover are preferred because they do not become weeds in subsequent seasons as do the vetches.

For vegetables, research conducted at the University of Maryland has shown that wheat—regulated with paraquat or glyphosate when 20 inches tall—has been successful in no-till production of most vegetable crops. If wheat growth exceeds 20 inches, then soil-water depletion by the wheat may reduce the subsequent emergence and growth of the vegetable crop. Hairy vetch drilled (7-inch spacing between rows) before October 15 at 20 lb/acre provides adequate ground cover for the no-till production of sweet corn, summer squash, and pumpkins. Vetch that has been flowering for 7 days can be regulated by mowing (flail type).

Table 15 gives seeding rates and planting dates for cover crops in Maryland.

Recommendations for Massachusetts

The most difficult cropping system that requires cover crops is silage corn. Farmers often harvest silage too late to allow successful cover-crop establishment when seeding after harvest. Aerial seeding has been successful and is strongly recommended. Research on the aerial seeding of cover crops

into sweet corn is in progress at the University of Massachusetts. The first-year establishment of hairy vetch, red clover, winter wheat, and annual ryegrass has been successful.

Comments

Research at the University of Massachusetts has focused on combinations of grain rye and hairy vetch for cover crops in sweet corn. Results have been successful using 56 lb/acre of rye and 40 lb/acre of vetch, and there is evidence that the vetch rate can be lowered to 30 lb. Successful cover-crop establishment has resulted when the crops were seeded in late August or early September. The cover crops are incorporated in mid-May to late May. The cover-crop combinations have been recommended for the following reasons: Vetch alone emerges more slowly in the fall than the rye and provides less erosion control; rye is much more efficient in “catching” nitrogen at the end of the year than is vetch; winter rye gives large quantities of biomass in the spring, adding more organic matter to the soil; and a few observations indicate that rye may help vetch survive the winter.

Additional research with oat/legume mixtures has been conducted. The legume species tested include hairy vetch, lana vetch, purple vetch, field pea, and lupin. To date, hairy vetch is the most promising species. With all of these legumes except hairy vetch, it is expected that the cover crops will winter-kill. Land preparation in spring is often accomplished with a light disking or with no-till (crop and equipment permitting) rather than moldboard plowing. These crops are seeded in late July or early August. This system is recommended for mixed-vegetable farms where crops are harvested at all times during the growing season. In addition to erosion control, these systems provide nitrogen; significant nitrogen responses have been documented, particularly in sweet corn.

Table 16 gives seeding rates and planting dates for cover crops for silage corn in Massachusetts.

Recommendations for New Jersey

Soil erosion on conventional-tilled soybean fields after harvest is a severe problem in New Jersey. On most fields, soybean residue left on fields after harvest is often inadequate, and conventionally planted cover-crop species are usually seeded too late to produce sufficient vegetation to prevent erosion. The establishment of small-grain winter cover crops is encouraged whenever feasible with the harvest schedule. In some cases, sowing into standing crops is encouraged. Winter wheat, barley, or rye is used as a green manure crop, or the wheat or barley may be harvested for grain and/or straw ahead of double-crop soybeans.

Although several cover crops with suitable characteristics for New Jersey conditions have been identified (annual ryegrass, field brome grass, and downy chess), cover cropping at present still generally relies on grain rye. Winter rye is drilled at a rate of 112 lb/acre (2 bu) by October 1 in northern New Jersey and by October 15 in southern New Jersey. When broadcasting and cultipacking, the rate must be increased to 168 lb/acre. The amount of seed required (224 lb/acre) and the high cost of aerial seeding at soybean leaf drop prohibits this method of seeding. The variety ‘Aroostook’ does not perform better than other varieties in this state.

The Cape May Plant Materials Center evaluated the aerial seeding of cereal rye, annual ryegrass, crimson clover, hairy vetch, wheat, oats, and black medic for their ability to establish in standing soybeans. The cover crops were seeded at 15-day intervals beginning in mid-August and ending in mid-October. It was found that the best seeding dates for cereal rye and ryegrass were September 1 to October 1. An August seeding date was too early because the soybean canopy prevented adequate light from reaching the ground. Use of earlier-maturing varieties of soybeans would enable earlier seeding dates. Mid-October was too late because the cover crops did not have time to establish good soil cover before the cold temperatures retarded growth. As a general rule, the overseeding of cover crops should be done when there is a 5 percent leaf drop in soybeans. Crimson clover, hairy vetch, wheat, oats, and black medic did not provide adequate ground cover during winter.

The use of cover crops for green manure is recommended for vegetable farms in southern New Jersey. Wheat, barley, or rye is commonly used in winter, and sorghum or sudangrass is commonly used in summer. However, wind erosion is a problem in the vegetable-farming areas along the mid-Atlantic Coastal Plain. The most critical problem is the airborne movement of sand particles across fields during periods of sparse soil cover. This can damage or destroy young plants by shredding leaves and breaking stems and—in extreme cases—uprooting or burying the plants. This type of damage results in yield losses, extra production expenses for replanting fields, and loss of the economic advantage of an early crop. It has become a recommended and widely used practice to leave 10-ft strips of small grains unplowed every 50–100 ft to serve as windbreaks early in the season for sensitive vegetable crops. The strips later serve as harvest access lanes. Rye is commonly used for this purpose. Earlier jointing and taller growth make it a more effective windbreak than either wheat or barley.

Another cover crop that has performed well under New Jersey conditions is subterranean clover. This is a winter annual forage legume that initiates growth in late summer or early fall, grows vegetatively until early winter, becomes dormant in winter, and resumes vegetative growth and flowers the following spring. Seeds are produced in a burr at

or below the soil surface (similar to peanuts), and the plant dies. This leaves a dead mulch layer, which covers the soil surface when the main crop is actively growing. Research at Rutgers University has shown successful use of this cover crop in no-till production of field corn, sweet corn, soybeans, summer squash, cabbage, and tomatoes. Current sub-clover varieties are not cold tolerant and may not survive winters in northern New Jersey.

Recommendations for New York

Silage corn is the major crop that requires the use of cover crops in New York. Winter rye, a traditional cover crop, is usually seeded after silage harvest to provide cover and to contribute organic matter to the soil. Rye is about the only species that will establish reliably in New York after silage harvest, and even rye frequently fails if seeding is done after October 1. When grain rye is used, care should be taken to use certified seed; 'Aroostook' is the variety of choice. If common rye is used, less early-spring growth can be expected. The recommended seeding rate is 112 lb/acre when seeded by August 10 in northern areas or by September 1 in southern areas. Later plantings require 168 lb/acre. Special herbicide programs may need to be developed to permit reliable cover-crop establishment.

Legume species will not produce much ground cover or biomass unless they are planted by August 20. So it is recommended that legume cover crops be seeded into standing corn. The earlier seeding allows both corn silage and corn grain producers to use cover crops and also increases the selection of species. Species seeded earlier in the growing season must be shade tolerant in order to grow under the corn canopy. Medium red clover, mammoth red clover, hairy vetch, crimson clover, alsike clover, white clover, ryegrass, fescue, and grain rye have been successfully seeded in corn at cultivation time in New York. It is recommended that interseeding be done when the corn is 6–24 inches tall. Research has also identified species that *do not* do well in standing corn: They include alfalfa, birdsfoot trefoil, oats, and sorghum. Main-crop herbicide programs will affect the success of cover-crop establishment. The choice of herbicides may need to be modified, or application techniques (banding instead of broadcasting) may need to be changed.

Cover crops are frequently used by vegetable producers who grow crops that are harvested in late summer or early fall (such as cucurbits, tomatoes, peppers, snap beans, and sweet corn). Where prevented by late harvests (cole crops, beets, potatoes, and drybeans), cover crops are difficult to establish. Some interseeding of small grains into cole crops is done by growers on Long Island. When planted after vegetable harvests, grain rye and winter wheat are the cover crops of choice. When interseeded, growers often use legumes—commonly the red and white clovers. There is

increasing interest in hairy vetch, but winter-hardiness zones in the diverse growing regions of New York are not well documented yet. There is evidence that mixtures of grain rye and hairy vetch may be more successful than either cover crop grown alone.

Cereal grains, which later serve as windbreaks, are seeded together with onions on about 80 percent of the muck soil production area in New York. This interplanting decreases the soil erosion in early spring and protects the slowly emerging onion seedlings from wind damage. In some years, whole unprotected fields of onions have been blown out of the soil. Barley is used on about 60 percent of these acres, followed by wheat. Some rye is also used. The grain cover crops are regulated with selective herbicides before they become too competitive and after the onions have several leaves and are firmly anchored in the soil. Table 17 gives seeding rates and planting dates for cover crops in New York.

Recommendations for Pennsylvania

Cover-crop establishment in silage corn and grain corn is best accomplished by interseeding at the last cultivation. Red clover is always successful, and good results have been achieved with hairy vetch interseeded when corn is 12–15 inches tall. Both broadcast and aerial seedings have been successful. White clover grows better when seeded with annual ryegrass than when seeded alone. Later plantings of vetch and the clovers are generally successful only when seeded as mixtures with grain rye. Interseeding in soybeans may be done between the time of leaf yellowing and the time of leaf drop, but not later than September 6.

The use of a perennial legume—crownvetch—as a living mulch is recommended by researchers at Pennsylvania State University. This living mulch reduces by 98 percent or more the water runoff, soil loss, and pesticide loss from sloping land. It provides a permanent vegetative cover. Crownvetch seedlings grow very slowly and normally require 2–3 yr to become a well-established, vigorous stand. Because few growers can afford to take a field out of production while establishing the cover crop, seedings can be made in corn, soybeans, or small grains. Seedings should be made with a broadcast seeder to the soil surface, or with a drill. A seeding rate of 5 lb/acre of inoculated seed gives a solid stand in 1–2 yr. A rate of 1 lb/acre band-seeded with a planter in rows as wide as 36 inches provides good stands in 3–4 yr. Herbicide programs in the main crops may need to be modified to allow the establishment of crownvetch. To obtain additional information on the various herbicide programs, contact Pennsylvania State University (Agronomy Department, University Park, PA 16802).

Living mulches are also recommended for use in tomatoes and other vegetable crops. It is recommended that 20 lb/acre

of annual or perennial ryegrass be broadcast after crop establishment, usually by mid-July when 50 percent of the soil between the rows is still open (not later than September 15). It is not necessary to cover the seed; the seed germinates after rainfall and grows slowly, without competing, in the crop. It is not necessary to mow either type of ryegrass. By harvest, a sod will have been established, making harvesting easier. Turf-type ryegrasses that are shorter may be used instead of common annual or perennial ryegrass, but the cost will be higher.

Recommendations for Vermont

The crops most commonly used for cover and green manure in Vermont are listed in table 18. The crops must be seeded no later than the dates shown to provide adequate cover for the periods indicated. When rye is aerially seeded into standing silage corn, the seed must have a minimum percentage germination of 80 percent. For this, 112 lb/acre will be required. Seed by August 10 in northern areas and by September 1 in southern areas.

Recommendations for West Virginia

Table 19 gives the crops most commonly used for cover in West Virginia, along with their seeding rates and planting dates.

Conclusion

Regardless of location, careful attention to the timely planting, selection of species and cultivar, and use of proper seeding techniques will provide adequate soil protection during those periods of the year when soils are most vulnerable to wind and water erosion.

Table 9. Growing degree days (GDD) by month at various locations in the Appalachian and Northeast region (from weather record during 1951-80 or 1961-90)

Location	Latitude	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Corrina, ME	44°57'	0	1	8	101	416	684	863	793	513	233	49	4
Montpelier, VT	44°12'	1	1	13	116	415	667	828	759	500	231	55	6
Durham, NH	43°8'	4	4	29	185	489	752	938	880	621	329	93	12
Ithaca, NY	42°27'	5	6	42	199	470	736	899	848	613	320	103	16
Amherst, MA	42°28'	4	5	40	232	552	808	979	918	658	365	114	14
Middletown, CT	41°33'	11	13	62	272	578	832	1013	957	697	416	159	30
Kingston, RI	41°29'	15	12	48	214	496	747	941	911	673	393	150	34
State College, PA	40°48'	10	15	72	288	596	832	985	937	691	377	127	22
Highstown, NJ	40°17'	23	29	112	347	651	900	1075	1032	791	480	199	50
Dover, DE	39°9'	52	63	188	448	758	984	1154	1117	897	584	274	94
College Park, MD	38°59'	46	62	199	469	773	994	1162	1123	885	550	245	77
Spencer, WV	38°48'	65	71	203	441	712	896	1034	1010	803	482	212	93
Williamsburg, KY	36°43'	13	18	92	257	459	690	821	759	584	264	86	18
Henderson, KY	37°45'	10	19	99	261	506	735	863	808	599	296	96	21
Crossville, TN	35°95'	11	22	89	216	408	602	734	710	506	219	77	25
Covington, TN	35°57'	19	35	134	327	582	804	933	875	656	346	128	35

Table 10. Species of cover crops recommended for the Appalachian and Northeast region

American common name	Latin binomial
Annual ryegrass	<i>Lolium multiflorum</i> Lam.
Perennial ryegrass	<i>Lolium perenne</i> L.
Winter rye	<i>Secale cereale</i> L.
Winter wheat	<i>Triticum aestivum</i> L.
Barley	<i>Hordeum vulgare</i> L.
Spring oats	<i>Avena sativa</i> L.
Field brome	<i>Bromus</i> sp.
Smooth brome	<i>Bromus inermis</i> Leyss.
Tall fescue	<i>Festuca arundinacea</i> Schreb.
Sudangrass	<i>Sorghum bicolor</i> (L.) Moench.
Sudan/sorghum hybrids	<i>Sorghum bicolor</i> (L.) Moench.
Orchardgrass	<i>Dactylis glomerata</i> L.
Foxtail millet	<i>Panicum miliaceum</i> L.
Pearl millet	<i>Pennisetum typhoides</i> (Burm. f.)
Red clover	<i>Trifolium pratense</i> L.
White (Dutch, ladino) clover	<i>Trifolium repens</i> L.
Crimson clover	<i>Trifolium incarnatum</i> L.
Subterranean clover	<i>Trifolium subterraneum</i> L.
Hairy vetch	<i>Vicia villosa</i> L.
Common vetch	<i>Vicia sativa</i> L.
Bigflower vetch	<i>Vicia grandiflora</i> L. (Scop.)
Lana vetch	<i>Vicia dasycarpa</i> L.
Crownvetch	<i>Coronilla varia</i> L.
Austrian winter pea	<i>Pisum sativum</i> ssp. <i>arvense</i> (L.) Poir.
Buckwheat	<i>Fagopyrum esculentum</i> Moench.

Table 11. Guidelines on additional cover-crop choices for Connecticut and Rhode Island

Species	Seeding rates (lb/acre)	Planting dates (fall cover)	Planting dates (winter cover)
Annual ryegrass	25–36	July 15	September 15
Field brome	10	July 15	September 1
Bigflower vetch	30		September 1
Hairy vetch	30		September 1
Wheat	120		October 1
Oats	96		September 15
Red clover	8–12	April-May 15	
Millet	20–30	May 1-June 30	

Table 12. Guidelines on planting specific legumes in Delaware

Species	Seeding rates (lb/acre)	Planting dates (from Dover south)	Planting dates (from Dover north)
Hairy vetch	20–25	August 1–November 1	August 1–October 15
Austrian winter pea	40–50	August 1–November 1	August 1–October 15
Crimson or red clover	10–12	August 1–October 1	August 1–September 20

Table 13. Seeding rates for cover-crop choices for silage corn in Kentucky

Species	Seeding rates (lb/acre)
Barley	72
Smooth brome grass	15
Tall fescue	15
Oats	48
Winter rye	84
Annual ryegrass	18
Hairy vetch	20
Bigflower vetch	20
Winter wheat	90

Table 14. Guidelines on additional cover crops for Maine

Species	Seeding rates (lb/acre)	Planting dates (fall cover, not field corn)	Planting dates (summer cover)	Planting dates (winter cover)
Field brome grass	20	August 15		September 1
Annual ryegrass	20	August 15		September 15
Winter rye	112	August 15		October 5
Winter wheat	100	August 15		September 15
Winter barley	96	August 15		September 15
Oats	80		June 15	September 1
Sudangrass	25		June 15	
Millet	20		June 15	
Red clover	10		June 1	

Table 15. Guidelines on additional cover crops for Maryland

Species	Seeding rate* (lb/acre)	Planting dates (Coastal)	Planting dates (Piedmont)	Planting dates (Mountain)
Winter annual grasses:				
Winter rye	120 (90–150)	September 1-October 15	September 1-October 1	August 20-October 1
Winter wheat	120 (90–150)	September 1-October 15	September 1-October 1	August 20-October 1
Winter barley	120 (90–150)	September 1-October 15	September 1-October 1	August 20-October 1
Spring oats	95 (60–125)	August 1-September 15	August 1-September 1	August 1-September 1
Annual ryegrass	20 (15–50)	September 1-October 20	August 15-October 15	August 1-October 1
Field brome	15 (10–20)	September 1-October 15	September 1-October 1	August 15-October 1
Winter annual legumes:				
Hairy vetch	20 (15–25)	September 1-October 15	August 20-October 1	August 1-October 1
Common vetch	60 (25–90)	September 1-October 15	August 20-October 1	August 1-September 15
Bigflower vetch	35 (25–40)	September 1-October 15	August 20-October 1	August 1-September 15
Crimson clover	15 (10–20)	September 1-October 15	August 20-October 1	N/A [†]
Subterranean clover	20 (15–30)	September 1-October 15	August 20-October 1	N/A
Austrian winter pea	80 (60–100)	September 1-October 15	August 20-October 1	August 1-September 15
Summer annual grasses:				
Foxtail millet	25 (20–30)	May 15-July 15	June 1-July 15	N/A
Pearl millet	20 (15–20)	May 15-July 1	June 1-July 1	N/A
Sudangrass	30 (20–40)	May 1-June 20	May 15-July 1	June 1-July 15
Sorghum X sudangrass hybrids	25 (20–30)	May 1-June 20	May 15-July 1	June 1-July 15
Spring oats	95 (60–125)	February 20-March 25	March 1-April 5	March 15-May 15
Buckwheat	80 (40–120)	May 15-July 1	June 1-July 1	June 1-July 1
Annual ryegrass	20 (15–50)	March 1-May 15	March 1-May 15	March 15-June 1

* The recommended seeding rate is given in lb/acre and should be used for normal seedbed conditions. Ranges are also given in parentheses. When a very good seedbed can be prepared or when a drill is used, the rate at the low end of the range can be used. When broadcasting seed, if planting later than the ideal time period or if planting in a rough seedbed, use the rate at the high end of the range.

[†] N/A = not applicable.

Table 16. Guidelines for cover-crop choices for silage corn in Massachusetts

Species	Seeding rates (lb/acre)	Planting dates (winter cover)	Planting dates (summer cover)	Planting dates (fall cover)
Annual ryegrass	25–35	September 15	May 1	July 15
Field brome	10	September 15		July 15
Bigflower vetch	30	September 1		
Hairy vetch	30	September 1		
Spring oats	96	September 15	May 1	
Sudangrass	25–35		June 15	
Buckwheat	50–75			July 15
Rye ('Aroostook')	112–168	September 14–30 (mountains); October 8–16 lower altitudes and coastal regions)		
Rye (common, 'Balbo')	112–168	Plant 1 wk earlier than 'Aroostook'		

Table 17. Guidelines on cover crops for New York

Crop	Minimum seeding rate (lb/acre)	Planting date (winter cover)	Planting date (summer cover)	Planting date (fall cover)
Annual field brome	20	September 15		August 15
Perennial ryegrass	15	September 15		August 15
Winter rye 'Aroostook'	100	October 1		August 15
Winter rye, common	100	September 15		August 15
Winter wheat	100	October 1		August 15
Oats	80	August 15	June 15	
Sorghum X sudangrass hybrids	30		June 15	
Millet	20		June 15	
Buckwheat	75		June 15	
Red clover	10		June 1	August 15

Table 18. Guidelines on cover and green manure crops for Vermont

Species	Minimum seeding rate (lb/acre)	Planting date (winter cover)	Planting date (summer cover)	Planting date (fall cover)
Field brome grass	20	September 15		August 15
Ryegrass	20	October 1		August 15
Winter rye ('Aroostook')	100	October 1		August 15
Winter wheat	100	October 1		August 15
Oats	80	August 15	June 15	
Sudangrass	25		June 15	
Millet	20		June 15	
Buckwheat	75		June 15	
Red clover	10		June 1	August 15

Table 19. Guidelines on cover crops for West Virginia

Species	Seeding rate (lb/acre)	Planting date
For corn:		
Winter rye	112	August 5-October 15
Winter wheat	112	August 5-October 15
Annual ryegrass	30	August 5-October 15
For gardens:		
Annual ryegrass	20	August 5-October 15
Winter rye	112	August 5-October 15
Rye or wheat + hairy vetch	56 + 20	August 5-October 1
For orchards:		
Annual ryegrass	20	September 10
Winter rye + hairy vetch	56 + 20	October 1
Winter rye	56-84	October 1
Field brome grass	20	September 15
Orchardgrass + ladino clover	8 + 2	Seed orchardgrass in April or May and clover in August and September

14 Management Options for Lands Concluding Their Tenure in the Conservation Reserve Program

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Most of the highly erodible lands contracted into the Conservation Reserve Program (CRP) had suffered much erosion, organic-matter loss, and structural deterioration while they were in cultivated crop production. When lands are returned to grass, their structure and organic matter improve and tend to approach the structure and organic-matter contents of the original grassland soils. But these improvements are rapidly lost as a result of tillage. So a critical question for managers of post-CRP land returning to crop production is how to maintain the benefits derived from 10 yr of grass. Going directly into no-till can be a cost-effective method of doing this.

No-till avoids the rapid biological oxidation of organic matter that results from moldboard plowing (Reicosky and Lindstrom 1993). It also maintains the pore geometry and continuity developed under grass. Macropores extending from the soil surface to deep within the root zone are maintained, resulting in high water-intake rates that reduce runoff and erosion. By keeping crop residue on the surface and keeping a few millimeters of highly organic soil near the surface, no-till also reduces evaporation. This combination of increased infiltration and decreased evaporation makes more water available for crop production and groundwater recharge. The additional groundwater increases the base flow into our streams from springs and seepage faces, and that base flow sustains the desirable components of our wetland ecosystems. No-till also reduces the populations of annual weeds that require soil disturbance for germination.

No-till production systems must be adapted to the conditions of the region and the resources and needs of the producer. The purposes of tillage include the control of weeds, insects, and pathogens. When tillage is discontinued, alternative means of controlling these pests must be used. Herbicides provide cost-effective control for most weeds. Other ways of controlling pests are mowing field borders before weed seed set; using disease-free and fungicide-treated seeds; rotating crops to break the life cycles of diseases, insects, and weeds; and narrowing the rows to allow earlier interception by the crop of the sunlight and nutrients that otherwise nurture the weeds.

Other chapters in this publication discuss the development of successful no-till systems. The following discussion in this chapter focuses on CRP: how grass affects soil properties, the rates at which grass improves soil properties, post-

CRP management options, the potential impacts of no-till after CRP, and some basic no-till guidelines.

Conservation Reserve Program (CRP)

The CRP was initiated in 1985 under the Food Security Act with the intention of placing up to 45 million acres of highly erodible farmland under protective cover. Public perceptions of the economic, social, and environmental state of farming before the initiation of the farm program influenced this multiyear land-retirement program. During this time, farm prices were low, large crop surpluses existed, farm foreclosures were increasing, and agricultural exports were decreasing. Lobbyists argued that these surpluses were preventing the improvement of grain prices and that due to these surpluses, large blocks of highly erodible land could be placed under protective unharvested grass cover. There was also public concern that current farming practices were destructive to both the soil's productive capacity and the wildlife habitat. Economists anticipated that the reduction in acres of grain would reduce grain production so that market prices would rise closer to target prices. Consequently, crop support prices would be lower per bushel and would be paid on fewer bushels. Based on these potentials for improving erosion control, farm prices, and the national budget, the CRP got under way.

Under this program, USDA pays CRP participants an annual rent for 10 yr, plus half the cost of establishing a conserving land cover. To be eligible for the program, land has to be potentially highly erodible or environmentally sensitive. A condition of this enrollment in CRP was that the farmers surrender their use of a proportional amount of their commodity crop base acreage. This subtracted base acreage is "returned" when the land is retired from CRP.

The objectives of CRP evolved during the program. The 1990 Farm Bill maintained an emphasis on soil erosion, but relaxed some erosion-control goals in areas where they would have imposed undue economic hardship on farmers. The new procedure used a productivity-based rental rate and ranked bids based on the ratio of environmental benefits index to the Government cost of the contract. Wetlands were included during two signup periods. U.S. conservation policy is moving to promote broader stewardship of all natural resources on the farm, as indicated by the addition of the Wetlands Reserve Program, the Agricultural Water Quality Incentives Program, and the Environmental Easement Program.

Status of CRP

By 1993, 36.4 million acres of highly erodible and environmentally sensitive land were enrolled in CRP. The first contracts will expire in October 1995. By October 1997, about 24 million of these acres will have been released. By

1993, commodity crop base acreage had been reduced by 23.3 million acres through enrollment in CRP. One of the major payoffs of CRP has been the significant improvement of wildlife habitat. This benefit has brought a major portion of the environmental groups to support CRP and the proposed related programs. The average erosion reduction on CRP lands is estimated to be 19 ton/acre/yr. Of the land that went into CRP, 2.4 million acres were planted with trees. This tree-covered acreage has a good start toward producing a harvestable timber crop, and will probably stay under tree cover for at least another 15 yr.

As these contracts approach their expiration dates, producers are questioning what the future holds for grassland enrolled in the CRP program. Many of the highly erodible lands accepted in CRP had suffered much erosion and structural deterioration. The organic-matter contents, soil structure, and infiltration rates of these lands have generally improved during their period in grass. However, these improvements may be rapidly lost during and immediately after tillage.

As CRP acres become eligible for release, landowners have many options, including leaving the acres in grass for hay or livestock production, or establishing some type of wildlife or recreation enterprise. Another option available to contract holders is to return all or a portion of the land back into crop production. Recent surveys indicate that over half of CRP contract holders plan to return to cropping after contract expiration. Many of these producers lack experience in dealing with the grass and the large amounts of residue accumulated after the land has lain idle for 10 yr.

Effects of Grass on Soil Properties

Soil structure influences the size, distribution, and geometric arrangement of pores in the soil for a given soil texture. These properties of soil pores determine the infiltration rates, internal drainage and aeration, water-holding capacity, and the portion of soil water that is available to plants. These characteristics tend to become optimized when there is sod cover. Soils with the best aggregation for crop growth in the United States are soils that have been in grass for many years. These soils—compared to cropped soils that are conventionally tilled—have greater amounts of organic matter, structural stability, total pore space, and air-filled pore space; higher hydraulic conductivity; and higher infiltration rates. Also, soils of long-term grasslands tend to have more pores in the size range that contributes to field water-holding capacity than do cropped soils.

All these characteristics result in improved water availability for plant growth. Earthworm channels connected to the soil surface reduce the runoff and improve infiltration into the root zone. Populations of earthworms have been

observed to be six to nine times higher in established grasslands than in cultivated soils.

Soils in long-term grass also show improved mechanical properties (such as increased moisture content at the lower plastic limit) that allow traffic and tillage under wetter conditions. When farmers till fine-textured soils following a long period in grass, they observe that the time periods between when a soil is too wet to till and when it is too dry to till decrease each year after tillage begins. These farmers plan the timing of their tillage operations based on these observations.

Soil aggregates from North American virgin grasslands are more stable than those from cultivated lands. The differences appear to be due to a cultivation-induced loss of particulate organic matter that helps bind small aggregates into larger aggregates. Particulate organic matter consists primarily of partially decomposed residue and roots. This fraction has a higher turnover than do other forms of organic matter and requires continual input into the soil. Grasses that form a sod cover are an excellent source of leaf and stem residue and of organic matter associated with continual turnover of an abundant fine root system. The superior aggregation qualities of grasslands result from the ideal conditions of simultaneous formation and stabilization of macroaggregates found in the grass rhizosphere. The reduced returns of root-system organic matter to the soil and the rapid biological oxidation of organic matter induced by tillage appear to account for the lower organic carbon and nitrogen found to a depth of 18 inches in long-term cultivated soils compared to those in virgin grasslands (Bauer and Black 1981).

When grasslands are cultivated, organic carbon and nitrogen decline most rapidly during the first 10 yr of cultivation and then decline more gradually, depending on cropping system and climate (Bauer and Black 1981). The soil structure deteriorates even more rapidly, with the greatest rate of destruction occurring in the first 2–3 yr after cultivation of long-term grasslands. The effects of tillage on soil properties after cultivation depend to some extent on the soil type. However, all soil types examined (loamy sand to clay) exhibit degraded soil physical properties resulting from tillage. Long-term tillage in these soils resulted in reduced water availability and aeration within the root zone. Pores containing water near the field capacity were reduced 14 percent by 12 yr of tillage on a Crowley soil in Arkansas (Scott and Wood 1989).

A major objective of CRP is the protection and improvement of the soil surface with grass cover. The grass cover protects the soil surface from raindrop impact and runoff, traps water temporarily in surface microcatchments, and allows the development of cracks and pores that open up the surface—all of which reduce the runoff and associated erosion.

Soil Improvement From CRP (Long-Term Grass)

Soil structure improves when cropped land is put back into grass. This is accounted for by the "land use residual" attributed to grass rotations in the development of cropping factors in the Universal Soil Loss Equation. Improved soil properties after grass can result in increased yields. Significant improvement in soil structure has been observed in 3–5 yr. However, more time is required for restoration of soil properties to the state found in the virgin soil. Mazurak and Ramig (1962) estimated that the effects of grass in a medium-textured soil in Nebraska reached its maximum benefit after 10–12 yr. Soil aggregate distribution, stability, air permeability, and hydraulic conductivity improved with time in the grass treatments. A review by Kay (1990) of the effects of grass on the rates of soil-structure stability improvement indicates that significant improvements will continue for at least 10 yr. As discussed in chapter 15, increases in organic matter are likely to continue after this time period but at a slower rate.

The management of grass influences the benefits of grasses on soil properties. Haying grassland slows the rate of change in soil structure (Mazurak and Ramig 1962). If a legume such as alfalfa is used in the grass mix, haying reduces most of the benefits of alfalfa to the soil nitrogen pool (Haas et al. 1976). Although haying slows the effects of alfalfa and grass on soil structure, improvement continues for at least 5 yr, as shown by the increased organic matter and aggregate stability.

The degree of soil improvement from 10 yr of grass is likely to depend on the soil and the site. As a general rule, the greater the amount of soil-structure deterioration from past cultural practices, the more likely that grass management will improve in agronomically important soil characteristics. Rasiah and Kay (1994) found that if soils had higher levels of organic matter and other stabilizing materials at the time of grass introduction, the time required for soil-structure regeneration was reduced. Soils in the CRP generally fit into the category of degraded soils whose organic matter is lower than that of surrounding soils, because they were primarily allowed into the program based on their "highly erodible" classification. Highly eroded soils tend to have reduced productivity, degraded soil structure, lower organic matter, and a less-than-ideal environment for root growth (Lindstrom et al. 1992). Soils that tend to be less stable and have less cohesion, such as sandy loams or compacted clay soils, may also benefit from the organic-matter inputs of 10 yr of grass. Soils with past deterioration or less-than-ideal physical characteristics are likely to be poorly buffered from tillage-induced changes and are most likely to rapidly lose the improvements derived from CRP when tilled. The surface of these less-than-ideal soils is also more likely to seal following tillage, which reduces the infiltration and increases the water runoff and soil erosion. A critical

question for managers of post-CRP land returned to crop production is, How can the advantages gained from 10 yr of grass production be maintained or prolonged?

Although the degradation of structure of soils taken out of sod and tilled is well documented, less is known about the effects of no-till cropping on lands previously in sod. Presumably the rate of decline is not as great for soils in no-till, because the reduction of or abstinence from tillage reduces disturbance of the structure and reduces the rate of biological oxidation of the organic matter.

Post-CRP Options

If funding can be obtained, the best approach environmentally for highly erodible CRP lands is probably to extend the contracts. This will allow the soils in the program to continue to improve and will keep erosion under control. Another proposal is to subsidize a rotation that involves 4 yr in grass production followed by 4 yr in grain production. Still another proposal is to lower the CRP payments to keep the lands in grass but to allow grazing or haying on these lands. The last proposal has met considerable opposition by farmers who have land already in hay production and who object to subsidized hay production that would compete unfairly with their product. The soundness of their arguments has been acknowledged by administrators and legislators. Consequently, it is unlikely that haying and grazing will be allowed on lands on which CRP payments are being made, except in emergencies.

Consequently, farmers who choose to use their post-CRP land for haying or grazing operations will have to pay their own way. In some areas of the United States, such haying and grazing operations on these lands can be economically viable if current hay prices can be sustained. However, the demand for hay is declining as the consumption of red meat declines, so the local hay markets are limited and the transport costs of hay are high. Thus major increases in production in any of these areas are likely to depress prices, so there will be little profit.

Another market that may develop for dry grass hay is its use as a fuel for power plants. Initial results from studies funded by the Department of Energy are encouraging, indicating that prices in the range of \$40–\$50/ton can be paid for dry hay for this purpose. However, the construction of power plants and the development of this market will take at least 10 yr, so this market will not be available to many (if any) farmers when their land comes out of CRP.

Since somewhat similar effects of supply and demand on price affect all of the markets for the products of these lands, and since small increments of supply generally cause less decrease in price per added unit of supply, individual farmers should evaluate the existing and developing markets

in their area before choosing their options. Existing commodity support payments will help protect farmers from decreasing prices for their products on the supported crops for which they have base acreage allotments. However, the long-term provisions of GATT will reduce those supports and expose farmers' returns from those crops to the fluctuations that are characteristic of the free market.

Possible options for farmers are as follows:

1. Maintain grass cover on the land.

a. Use management for hay production. Hay management is designed to avoid disturbance of nesting birds. An example is to delay the first cutting until danger of disrupting nesting birds is past.

b. Graze animals on the land. Rotate grazing areas to minimize disruption of nesting birds and grass deterioration.

c. Manage the land to preserve wildlife. This can include development of fee hunting preserves, etc., and may be combined with some of the other options where provision of improved wildlife habitat is designed as part of the conservation plan.

d. Extend the CRP contract, if possible.

2. Return the land to cropping.

a. No-till into sod. Use low-disturbance systems with appropriate rotation systems to manage weeds, pests, and fertility without a dramatic increase in purchased inputs. Maintain surface residue and soil structure.

b. Use a wide V-blade sweep to undercut sod. Then use no-till planting or minimum-till air-seeder methods of production.

c. Use a moldboard or chisel plow followed by a no-till system. Use plowing to remove the initial residue followed by no-till, to maintain residue of subsequent crops on the surface.

d. Use only conventional tillage. The tillage system and rotation must be modified to fit the conservation plan developed for conservation compliance, if required.

e. Create a meadow and rotate with crops. Rotate grass or a grass-legume-forage mixture or both among fields, to reduce the average annual erosion rates.

For most CRP lands where contracts cannot be renewed, no-till management appears to provide the greatest potential for achieving reasonable net returns while retaining most of the soil-quality improvements achieved during the CRP.

Since this option has potential for achieving objectives expressed by most farmers, a special section is included in this chapter to further describe how CRP lands can be cost effectively transitioned to economically and environmentally sustainable production systems. Further details about no-till and conservation management of surface residue are described in other chapters of this publication.

No-Till After CRP

Cropping practices that avoid tillage have the advantage of avoiding the rapid mineralization of carbon and nitrogen that occurs when grass or crop residues are mixed with the soil by tillage. Reicosky and Lindstrom (1993) measured the release of carbon dioxide from moldboard-plowed wheat stubble and found that carbon loss in 19 days after plowing was greater than the carbon contained in the stems, leaves, chaff, and roots of the previous wheat crop. Their treatments included no-till, disking, chisel plowing, and moldboard plowing, and the rates of biological oxidation of organic matter increased in that order, with the oxidation of organic matter from the no-till area being about 15 percent of that from the moldboard-plowed area. Lamb et al. (1985) measured soil organic nitrogen losses in the top 12 inches of a soil that had been in native grass and was then cropped to winter wheat for 12 yr in a wheat-fallow system. Nitrogen loss was 3 percent for no-till, 8 percent for stubble mulch, and 19 percent for plowed (black fallow).

Evaluation of organic carbon and nitrogen levels after 10 yr of no-till or conventional-tilled corn production in a Kentucky soil that had previously been in bluegrass sod showed about twice the carbon and nitrogen amounts in the surface soil layer of no-till (Blevins et al. 1983). Organic carbon and nitrogen levels did drop with corn production for both tillage systems, but could be maintained under no-till management—with good lime and fertilizer additions—near the level found in the bluegrass sod.

Intensive tillage will rapidly change the physical state of a soil that has been in sod. The first change that occurs with tillage is the breaking of the continuity of established soil pores. Chan and Mead (1989) measured a high degree of water-transmitting macropores in a permanent pasture that had been lightly grazed. Cultivating to a depth of 4 inches for 4 yr completely disrupted this macropore structure and resulted in increased water runoff by reducing preferential flow within the macropore network and altering the pathway of infiltrated water movement. In contrast, the macropore system remained intact with no-till crop production.

One would expect no-till production systems after sod to slow the rate of loss of soil-structure stability since there is no disturbance of existing soil structure. However, in most cropping situations (no-till and conventional tillage), carbon input from root systems will be reduced and a loss of soil-

structure stability over time might be expected, compared to those in grass sod. The benefits from no-till on soil structure result from a reduction in structural degradation, especially at the soil surface. The exact extent to which no-till can prolong the benefits of grass sod has not yet been determined. However, no-till systems introduced to tilled fields significantly improve soil surface characteristics when abundant residues are produced. This aspect alone is expected to improve infiltration and reduce erosion. The provision of optimum crop nutrients and the use of cover crops with no-till allow additional residue production and carbon input into the soil. A study in Kentucky (Ismail et al. 1994) found that organic carbon content was restored to that of a bluegrass sod after 20 yr of fertilized no-till corn with a rye winter cover crop.

No-till management systems have been shown to increase soil organic-matter content and improve the soil structure in soils having low organic matter and poor structure. However, the structural improvements achieved during 3 yr of no-till were eliminated with one moldboard plowing (Kladivko et al. 1986). Improvements in soil structure with no-till are not obtained immediately. As discussed in chapter 15 (long-term effects), several years are often required before significant soil-structure improvements can be documented. Soil erosion from either wind or water is reduced with the onset of no-till management simply because surface residues protect the soil surface from erosive forces. Water runoff is generally reduced with no-till, but not always. The CRP lands present many opportunities to initiate no-till in a situation where soil organic-matter contents, soil structure, and infiltration rates have already been improved.

In eastern South Dakota on land that had been in alfalfa-brome-grass sod for 6 yr, Lindstrom et al. (1994) initiated moldboard plow, chisel plow, and no-till corn production systems and obtained similar yields on all systems. In the fourth year of production, immediately after planting, artificial rainfall was applied at a rate of 2.5 inch/hr for 1 hr on one day and then again the next day on each of these management systems and on the undisturbed alfalfa-brome-grass sod. No water runoff or soil loss occurred from the area that was still in the sod or from the areas that had been in no-till corn production. But water runoff from the moldboard-plow tillage systems was 49 percent of the total water applied, and runoff from the chisel-plow-based tillage system was 34 percent. Soil loss was 11.8 ton/acre from the moldboard-plow system and 2.4 ton/acre from the chisel-plow system.

In the northern Corn Belt, conversion to no-till from a moldboard-plow row-crop production system has not always resulted in improved infiltration (Lindstrom et al. 1981, Mueller et al. 1984). The initiation of no-till row-crop production in a sod did exhibit higher infiltration than did the tilled systems. The improvement in organic matter, soil

structure, and infiltration that occurred under the 6 yr of brome-alfalfa growth was maintained with no-till into the fourth cropping season, with no indication of soil degradation with the no-till cropping. The development of soil macropores that extend from the surface to deep within the root zone and that are open to the atmosphere and protected by residue cover result in high infiltration rates, reduced runoff, and subsequently reduced soil loss.

In the early 1970's, innovative farmers in the southern Appalachian hill country used paraquat and atrazine to kill fescue grass, and also used newly available no-till planters that cut through the sod with fluted coulters to plant corn without tillage. The resulting yields in some cases exceeded 200 bu/acre (Box et al. 1976), which was the first time that yields on unirrigated land in this area had reached those levels. A substantial portion of this high yield was attributed to sustained high infiltration rates and lowered evaporation rates, which made more of the water available for crop use, compared to the available water in conventional tillage systems. No-till planting into sod is a cost-effective means of erosion control in the Appalachian and Northeast region, which can be used to bring CRP and other grasslands into production as needed. As shown by Lindstrom et al. (1994) and discussed in chapter 15 (long-term effects of tillage), no-till management retains most of the benefits accrued by soils during their tenure in grass.

Systemic herbicides can obtain a good kill of grass after the grass has been cut and begins vigorous regrowth. However, if the grass is dormant or under stress, such as may occur in regions where water is limiting in the summer and fall, then a systemic herbicide will give poor control. In situations where cool- and warm-season grass species are growing together in CRP land, a systemic herbicide may need to be applied twice to avoid dormant periods.

A primary restriction to such timely application of the needed herbicides may be the rules related to preparation of the land for its use following the CRP contract. The contract agreement states, "The participant shall maintain the vegetative cover and the required conservation practices on the land which is subject to this Contract and take other actions that may be required to achieve the reduction in erosion necessary to maintain the production capability of the soil throughout the contract period."

In view of the need of farmers growing winter wheat to plant in the fall and the need for some land preparation before the wheat is seeded, current rules allow farmers to begin such preparation, including tillage, up to 3 mo before the October 1 release of such lands. If tillage—which buries the residues and disrupts and displaces the sod fabric—takes place, it will expose the soil to erosion and rapid decreases in organic matter and infiltration. But if the needed killing of the grass is accomplished with a herbicide, the grass residues and sod will remain in place and protect the soil

from erosion during the period it is accumulating the water needed to germinate the seed and facilitate the growth of the following crop. Observations indicate that the intact slowly decaying residues and sod will keep infiltration rates high and will control erosion for at least a year following killing of the grass.

Burrowing animals become established in some CRP land during the 10-yr period of grass. These animals tend to cause the soil surface to be quite rough (Kalisz and Stone 1984). The farmer's inclination, following the CRP contract, may be to moldboard plow the area before starting no-till. And in extreme situations, this may be required. But once the grass is killed and a crop has been planted, the food source is removed, the animals disappear, and the mounds tend to level within the year.

Nitrogen management on no-tilled former CRP lands also needs special attention because of changes in nitrogen mineralization patterns (Wood et al. 1991a, 1991b). As tillage intensity is reduced, microbial oxidation of organic matter decreases and more of the organic nitrogen is retained in the organic matter with the soil. Soil testing is critical, and the subsequent soil-fertility recommendation must take into account the effects of the 10-yr period of grass and lack of a primary tillage operation. No-till into sod will initially require higher nitrogen rates than will a moldboard-plowed sod (Thomas et al. 1973) because the plowing accelerates biological decomposition of the organic matter and mineralization of its nitrogen.

Design of No-Till Systems

No-till systems must be designed according to the unique conditions of the region and the specific needs of the individual producer. Therefore it is not possible to design a no-till management system that can be applied at all locations across the United States or even within a single region. A successful no-till system must be developed from a whole-system point of view. Simply stopping tillage with no other changes in the cropping system increases the potential for problems and failure. Three principles that need to be considered in designing a no-till system are rotation, sanitation, and competition to help control weeds, insects, and pathogens (Beck and Doerr 1990). Although the specific cultural practices required for each region and farm are likely to vary—depending on climate, crop, and local markets—these three broad-based principles are common to the successful establishment of no-till. Other chapters in this set of Regional Conservation Reports provide additional details on how to adapt no-till and other types of crop residue management to specific soil, climate, and crop situations.

Sanitation includes practices that reduce the movement and spread of pests (weeds, diseases, and insects) into a field. An example is the prevention of perennials from producing seed in the field borders by mowing. Another is the use of disease-free seed. Many of the agronomic practices in this category are well known. The importance of following these practices is more critical in no-till systems because the practices become a more critical line of defense against pests when tillage is removed from the operations.

Rotation is especially critical to a properly designed no-till system. Rotation can be beneficial in controlling weeds, disease, and insects by breaking the life cycles that depend on compatible crops or by increasing the competitive pressure on a pest during part of the rotation. An example is the use of a corn/small-grain/soybean rotation to protect against corn rootworm infestations with extended diapause. The use of rotations in no-till generally helps create a stable, low-maintenance cropping system. The design of rotations should consider the best cropping sequence for control of diseases, weeds, and insects; soil temperature at planting; seed zone moisture content; residue cover for erosion control; and labor and equipment use.

Making the best use of competition is achieved by manipulation of the crop so that it can outcompete the weeds for resources such as light, water, and nutrients. An example is the use of narrow spacing between rows to achieve early and rapid canopy cover. Cover crops may also be manipulated in the more humid regions of the United States to compete with weeds, add nitrogen, and protect the soil during noncropping periods.

No-till equipment has been designed for most crops. But care must be applied in the selection of no-till equipment to ensure that the methods of chemical application preferred by the producer are compatible with that equipment. Also, equipment modifications may need to be made regionally, depending on climate- and soil-specific problems. For example, in the northern parts of the Corn Belt and the Cotton Belt, row-clearing attachments may be needed to remove some of the residue from the row area. This removal will allow soil warming for improved seed emergence, especially in poorly to somewhat poorly drained areas.

Other aspects that should be included in the design of a no-till system are time utilization, equipment use, livestock needs, personal preferences of the producer, cash-flow requirements, market availability, predictable climatic patterns, aquifer location, soil fertility, and risk management. Planners of no-till must rely on specific management practices and equipment that are adapted to the region, and/or develop practices and modify equipment to adapt to the unique characteristics of an individual site.

Conservation Measures for Residue-Deficient Crops

When the primary cash crop suited to the area is a residue-deficient crop such as cotton, there may not be sufficient residue during the year following the cash crop to provide the mandated erosion control. As discussed in chapter 13, cool-season cover crops are often a good provider of the needed protection. Where the growth of cover crops results in water deficiency or is otherwise not feasible, grass hedges—which retard runoff, pond water where they intercept flow concentrated in rills and gullies, and retain most of the sediment—can often complement no-till management to achieve the needed erosion control (Kemper et al. 1992). To be most effective in the concentrated flow channels, grass in these hedges should be stiff-stemmed and tall because they must stand erect to achieve the needed retardation of the flow (Dabney et al. 1993). In the few cases where the grass planted into the CRP lands has tall and stiff stems (for example, switchgrass or eastern gamagrass), the needed hedges can be achieved by leaving living grass in strips 2 or 3 ft wide between strips of planned cropped area, whose width is about 10 times the grass height.

If grass on the CRP land is not sufficiently stiff and tall to provide the retardation and dispersion of the concentrated flows, CRP rules allow improvements of the cover during the contract period. Since most perennial grass species require about 2 yr to reach maximum stature and get their roots below those of annual crops, the rows of tall grass for hedges will be better prepared to thrive and to protect the cropped area if they are planted a year or two before crops will be planted. This can be accomplished by killing the grass strips within the CRP land with herbicides and planting them with the desired tall, stiff-stemmed grasses. When these hedges have reached the desired height and the CRP contract rules allow killing the grass in preparation for planting the crop, the short grasses in the planned crop strips between the hedges can be killed. To avoid the potential for being considered in violation of CRP rules, the installation of tall-grass hedges in CRP lands should be discussed with your Natural Resources Conservation Service (NRCS) District Conservationist and incorporated in your approved plan before you kill the grass strips.

The costs of this additional improvement of CRP lands to provide tall-grass hedges for erosion control of subsequent croplands cannot be shared by the CRP. However, since less than 10 percent of the area is in the grass hedges, the cost for herbicide and seed is small.

Although game birds have been observed nesting and overwintering in tall-grass hedges, there has been no systematic evaluation of the effects of these hedges on bird populations.

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15 Long-Term Effects of Tillage and Residue Management

W.C. Moldenhauer, W.D. Kemper, and R.L. Blevins

Soil Genesis and Degradation

When Europeans arrived in America, they found soils that were a result of climate and vegetation interacting with the geologic minerals. Leaves and other residues fell to the ground and decayed, and part of their decomposition products leached into the soil. Roots grew, died, and decayed and also contributed to building the organic matter and associated elements that nurtured the natural successions of plants. Among these plants were legumes that provided photosynthate to bacteria infecting their roots; these bacteria were able to take nitrogen out of the air, fix it in ammonium, and share it with their host plants. Primarily as a result of these legumes, about 6 percent of the residual organic matter in soils is nitrogen. Other plant nutrients extracted from the soil and air and incorporated into the plants also became part of this soil organic matter. Although most native Americans were crop growers, they were few. Their methods of crop production involved little tillage. Competing weeds were removed largely by hand.

Friendly natives taught the newly arrived Europeans how to grow corn in the early 17th century. With their iron mattocks and hoes, the Europeans were able to control weed growth more efficiently than were the natives. Within a few years, corn was the staple of their diet, and they were growing enough corn to trade it for animal furs. The arrival of draft animals, cultivators, and plows gave the Europeans additional ability to control weeds. These implements also stirred and aerated the soil, buried crop residues, and stimulated microbial activity, which increased the rate of breakdown of the residual organic matter, liberating its nutrients for use by the crops. Since there were no commercial fertilizers, this accelerated decomposition of organic matter was the primary source of plant nutrients in those early years.

In the 19th century, the moldboard plow—which turned the soil over completely and buried almost all crop residue—became the most popular implement for primary tillage. The complete burial of the crop residue exposed American soils to the beating action of raindrops; this action destroyed soil aggregates, filled the large pores, and reduced infiltration—all of which caused runoff and erosion. Erosion by runoff water carried away substantial portions of the topsoil in the eastern and southern portions of the United States where rainfall rates were high. In the more arid western plains, the burial of plant residues and the subsequent raindrop beating created smooth surfaces along which sand grains could be

accelerated by the wind until they literally sandblasted the soil and enabled the wind to blow away major portions of our topsoils.

In the early 20th century, concerned farmers and Government officials recognized the rapid degradation of our soils due to erosion and initiated research and action plans designed to reduce erosion. In the 1920's and 1930's, rotations, stripcropping, and mulch tillage were evaluated. These techniques involved chisels and blades that sliced under the soil surface and killed weeds but left most of the crop residues on the surface. They obviously helped to reduce the erosion from wind and water. It took longer to observe their effects on organic-matter content and fertility of the soil. Long-term studies were initiated at several locations across the country. For instance, at Urbana, IL, the Morrow plots were established in 1876. The organic-matter levels of this soil were over 6 percent when European Americans began tilling them. Continuous corn, involving plowing each year, has reduced the organic-matter content to less than 3 percent (fig. 13). The best rotations reduced the rate at which this organic matter was depleted, and legumes in those rotations helped maintain soil nitrogen. But organic-matter levels continued to decline as long as plowing continued.

At Pendleton, OR, residual-organic-matter content of soil under grass was reduced under moldboard plowing, which accelerated the runoff, erosion, and loss of fertility. Consequently, in 1929 researchers began evaluating a series of crop-residue management treatments ranging from burning the residues to plowing 10 tons of manure plus the crop residues into the soil each growing season. Refraining from burning slowed the rate of decline of residual organic matter, and during the first 20 yr the heavy manure additions seemed to slightly increase the organic-matter content of the soil (fig. 14). However, even with 11–12 tons of organic residue plowed into the soil each growing season, the residual-organic-matter content of this soil has not increased during the past 40 yr (Rasmussen et al. 1989).

Reicosky and Lindstrom (1993) measured the carbon dioxide given off in fields during 19 days after wheat stubble had been moldboard plowed, chisel plowed, disked, or left standing with no-tillage. As shown in figure 15, the amount of carbon oxidized was greatest in fields that had been moldboard plowed. In 19 days, as much carbon was oxidized as had been photosynthesized and incorporated into the residues and roots during the whole growing season. A large portion of the crop residue had not completely decomposed at the time. Consequently, it appears that easily decomposable portions of the fresh residue had provided food to generate high microbial populations, which then found access to residual organic matter in the plowed and highly aerated soil, and oxidized substantial amounts of it out of the soil. When one realizes that microbial oxidation

can oxidize a couple of tons of organic matter in 19 days following moldboard plowing, it is easy to see how 12 tons could be oxidized, after being plowed into the Pendleton plots, during their 2-yr fallow-crop cycle.

Other types of tillage resulted in lower biological oxidation rates (fig. 15) than did moldboard plowing. Their use (instead of moldboard plows) has helped to slow the rate at which residual organic matter has been oxidized out of our soils. However, during the Reicosky and Lindstrom study, the oxidation of organic matter from all tillage treatments was much more than that from the no-till treatment.

Effects of Reducing Tillage on Residual Organic Matter

Wide V-blades, rod weeder, and other equipment that disrupts the soil and undercuts the weeds but leaves most of the crop residue on the surface have helped to control erosion (Lindstrom et al. 1974). As relatively low-cost fertilizers became available, it was no longer necessary to till and oxidize our organic matter to release nutrients needed by our crops. The development of herbicides provided an alternative to tillage for weed control. As conservation-minded researchers and farmers saw the improved erosion control that resulted from leaving residues on the surface, they used these alternatives and reduced the tillage. Some of them reasoned that growth of grain crops was now possible in systems more similar to those in our natural ecosystems, where there is no tillage.

In these natural systems, when vegetative growth is good and burning has not occurred, the soils generally had continuous cover and protection from the eroding forces of wind and water. The major obstacle remaining to leaving residues on the surface was getting seed through mulches on the surface and into the soil. Equipment companies helped to develop coulters, seed-placement devices, and press wheels that cut through the residues without disturbing them appreciably and allowed seed to be pressed into good contact with the soil. The development of no-till drills and seeders provided an alternative to seedbed preparation, which has been the other major purpose of tillage. With these alternatives to tillage available, thousands of fields were soon managed without tillage.

The erosion-control benefits of no-tillage were immediately obvious. Researchers documented that no-till reduced erosion to 0–20 percent of that occurring under moldboard plowing systems. By removing crop residues from some of their no-till plots and observing erosion during rainstorms, researchers found that the absence of tillage, in addition to keeping protective residues on the surface, leaves the soil more cohesive and more resistant to the erosive forces of water. Measurements in laboratories showed that bonding forces between soil particles are decreased by tillage and

then increase with time following tillage. The root fabric and the high residual-organic-matter contents that develop under the residue cover in the top few millimeters of the soil under no-till management reduce the slaking and disintegration of aggregates when they are wetted.

In the past, we believed that tilling crop residues into the soil was the way to get these residues down into our soils where they can help to build up the residual organic matter. The findings of Reicosky and Lindstrom (1993) showed that this intuitive feeling was wrong. In fact, incorporating crop residues into the soil by moldboard plowing accelerates the rate of oxidation of both the crop residues and residual organic matter.

Farmers practicing no-till management have noticed that their soils are becoming visibly darker. Researchers in Ohio, Georgia, Alabama, and Colorado measured the residual organic matter in no-till soils and found that it was increasing. This increase in organic matter is greatest in the top few millimeters of soil (see fig. 4 in ch. 5), where it is most important for reducing the slaking and surface sealing. Where substantially increased organic matter has been observed to depths of up to 10 cm (for example, fig. 16) in some fields that have been “almost no-till,” the small amount of tillage performed (one light disking each year for 10 yr) (Edwards et al. 1992) substantially homogenized the organic matter increases throughout the cultivated layer. So in natural conditions, how does the organic matter get down several inches into the soil? Water passing through organic residues into soils often carries over 100 parts per million of dissolved organic matter; so 3 acre ft of water leaching through the residue can carry 1,000 lb of organic matter into an acre of soil. Decaying roots and root exudates also add up to 1,000–2,000 lb of organic matter per acre per year. A major portion of this organic matter is used as an energy source by microorganisms, but much of it is incorporated into tissues of the microorganisms, portions of which become part of the residual organic matter. Earthworms and other burrowing animals and insects also help to mix organic matter from the plant residues on the surface into the soil.

Operations that incorporate seed and fertilizer, or roughen the soil surface to help germinate seeds, or facilitate the use of special equipment also assist in mixing organic matter into the soil.

Measurements of residual organic matter in soils during 10 or more years of no-till management indicate increases ranging from 0 to 2,000 lb/acre/yr. These rates depended on how much crop residue was left on the surface. The highest rates of increase occurred where crop residues were augmented with winter cover crops that had all been left on the surface (Edwards et al. 1992, Langdale et al. 1992b). The lower rates were from drier warm regions where the amount

of crop residues was limited and the high temperatures caused rapid biological oxidation of the organic matter.

In areas where residual soil organic matter is low, organic wastes such as paper and manure have been placed on the soil surface or plowed into the soil to help increase the organic matter. The greatest sustained increases in residual organic matter are occurring where there is no tillage and the organic wastes are left on the soil surface (Edwards 1994).

Because the elimination of tillage can increase the amounts of organic residues left on soil surfaces, can decrease the rates of biological oxidation of residual organic matter, and can reduce soil erosion, the elimination of tillage can result in net increases in residual soil organic matter. No-till and reduced tillage can conserve our soils but can also enhance them so that they will be able to sustain the world's growing population.

Effects of Leaving Crop Residues on the Surface

Effects on Soil Fertility, pH, and Rooting Depth

As the early practitioners and critics of no-till contemplated the potential problems of this management system, one of their concerns was to get fertilizer and lime from the surface down to the crop roots. To some extent, the feeder roots of the crops solved this problem by coming up nearer the soil surface where the soil is moister (because crop-residue mulches reduced evaporation from the soil).

Phosphorus was expected to be a problem because it is normally adsorbed and is relatively immobile in soils. However, as Kunishi et al. (1986) found, phosphorus apparently forms complexes with organic matter when left on crop residues on the surface, and these complexes leach down into the underlying soil where they are readily available to feeder roots. Beneficial mycorrhizae associated with roots extend their long slim hyphae into the soil and allow plants to draw phosphate from parts of the soil not directly reachable by the roots. More of these hyphal conduits remain intact when tillage does not occur. Crop roots in no-till soil tend to follow root channels of the previous crop, where they are tied into more quickly with this hyphal conduit system, which helps them extract water, phosphorus, zinc, and many other elements from the soil.

Calcium has historically been observed to stay close to where the lime was placed in soils, and we wondered whether lime applied on the surface would stay there and leave the underlying soils excessively acid. Some of the early no-till researchers found that the immediate surface of no-till soils was becoming acid sooner when urea and ammonium-type fertilizers were broadcast on the surface.

When lime was broadcast on a fertilized surface, it seemed to move down into the soil more quickly. In long-term no-till fields (fig. 17) where the lime, crop residues, manure, and nitrogen fertilizer have been left on the surface for 24 yr, the acidity of underlying soils has been neutralized to a depth of about 70 cm, compared to 30 cm where soils have been plowed and lime has been mixed into the soil.

The mechanisms by which the calcium in the lime is mobilized probably involve the concentration of crop residues, nitrogen fertilizer, and lime at the surface. As ammonium fertilizers are nitrified by microorganisms to nitrates, acid hydrogen ions are produced, which tend to solubilize the calcium in lime when it is close to the fertilizer. The slow and relatively continuous biological breakdown of the surface residues produces a continuous source of organic anions, which along with the nitrates provide companions that facilitate the downward leaching of positively charged calcium and the displacement of aluminum and hydrogen ions from the root zone.

For years, researchers have been trying to get more calcium into subsoils, raise the pH of subsoils, and cause them to be more hospitable to roots. Deep plowing and mixing of lime into the subsoil worked but were too expensive. These benefits can occur as a side effect of no-till leaving all the residues, fertilizer, and lime on the surface. When the nitrogen fertilizer is knifed into the soil, the subsoil pH still tends to increase from surface lime application; but this moderation of subsoil acidity is not as great as that noted when nitrogen fertilizer is applied on the surface.

Sumner (1990) was able to increase alfalfa rooting depths in acid soils by 50 percent by getting calcium into acid subsoils using gypsum applications that did not involve disturbance of the subsoil. Wang et al. (1986) found that earthworm burrows in the soil facilitated deeper rooting of soybeans. Since long-term no-till management generally increases earthworm populations and depth of calcium penetration, these two factors are probably acting together to facilitate deeper rooting. Deeper rooting provides the plants with access to more soil water, which probably helps account for the increased drought tolerance of crops grown under long-term no-till management on fields that initially had acid subsoils.

For producers to take advantage of greater growth potential due to the additional water conserved under minimum-till or no-till systems, additional fertilizer nitrogen is needed. Some of this nitrogen will be incorporated as part of the increasing residual-organic-matter content of the soil. The quantity of nitrogen fertilizer needed after several years of cropping in minimum- or no-till systems may decline as residual soil organic matter becomes sufficient to supply more nitrogen for plant use.

Effects on Infiltration, Evaporation, and Water-Use Efficiency

The most direct and measurable effect of keeping crop residues on the soil surface is the improvement of the water-use efficiency of acid and calcareous soils. In many areas, the increases in infiltration rate and the decreases in evaporation due to crop residue cover occur within a year or two; they are discussed in previous chapters. However, in soils where earthworm populations were previously decimated by intense cultivation, it may take many years to bring the earthworm populations back to where their burrows to the surface contribute significantly to infiltration.

A series of small watersheds near Coshocton, OH, were brought into no-till management 1, 2, 5, 7, 9, and 21 yr before measurement of the amounts of large-size porosity (fig. 18) (Norton and Schroeder 1987). These measurements indicated that in this soil, it took 6–7 yr for the earthworms to return in large numbers. The researchers measured pores at the soil surface that were larger than 0.5 mm, which are highly effective in letting water through surface seals into the soil. Earthworms and recent cultivation are factors that are commonly responsible for such large pores. After the cessation of cultivation, the percentage of surface occupied by these large pores declined for 5 yr. It was only when the earthworms returned in large numbers in the sixth and seventh years after the beginning of no-till management that their burrows furnished enough of the large pores to contribute significantly to the rapid entry of water into the soil.

The return of worms has been hastened by collecting buckets of them from lawns and the edges of rural roads during or immediately after rains and then depositing them in new no-till fields. The worms need to be placed in groups of four or five to increase the probability of reproduction. They will invade a soil at a rate of about 50 ft/yr when conditions favor their growth. However, their lack of a specific urinary tract leaves urea on their skins, which hydrolyzes to ammonia and irritates them. Consequently, they are attracted to moist soils where they can rub off the urea and ammonium more quickly and also to the surface during rainfall events, where the rain washes these offending compounds off their skins. The tendency of the worms to come to the surface during rainfall contributes to their migration during runoff events, when they float downhill. In 945-ft² runoff plots at Kingdom City, MO, as many as 900 earthworms have washed off a single plot in a single rainfall event. Although the average rates of downstream transfer of worms are probably lower than those in this example, their rate of return to the whole field can be significantly increased by introducing the worms on the higher portions of fields.

As soon as crop residues accumulate and provide cover for most of the surface for a significant part of the year, they

help reduce evaporation from the soil. Long-term no-till practitioners report that the amount of crop residue returned to the field increases with time for 10 or more years as crop yields increase. However, some long-term no-tillers have noted that high populations of the night-crawler-type earthworms result in more collection of residues (especially after soybeans) into their middens (holes) and faster removal of the residue cover from the soil. Fortunately, this process does not usually deprive the soil of cover until the crop canopy has begun protecting the soil from raindrop impact. Even when the lack of surface cover allows sealing of a major portion of the soil surface, the presence of several earthworm middens per square yard will drain most of the water accumulating on the surface down into the soil and thus minimize runoff.

Another long-term effect of keeping residues on the soil surface that will contribute to water-use efficiency is the accumulation of residual organic matter. As discussed earlier, this is a slow process, occurring at rates of about 1,000 lb/yr under good no-till management. This takes 20 yr to increase the organic-matter content of the top 6 inches of soil by 1 percent. In soils like those in the Morrow plots in Illinois, which initially had organic-matter contents of over 6 percent and are now down to near 2 percent, it could take a century of good no-till production to restore them to 6 percent organic matter.

Recent analyses by Hudson (1994) showed that in loam soils the available water-holding capacity of the soil is increased by almost 4 percent of the soil volume by each additional percent of residual organic matter in the soil. For farmers who have topsoils with low organic matter and water-holding capacities of 10–12 percent, this gives them the potential of increasing those capacities to 14–16 percent in 20 yr. If this organic-matter buildup and increased water-holding capacity are restricted to the top 6 inches of soil, the soil will hold an extra 1/4 inch of water each time it dries out and is refilled by rain. Thus the total amount of extra water held during all the refills during a growing season will be only 1 or 2 inches. However, most of the crops' feeder roots are in this layer, so the crops will have better access to nutrients as well as water during drought-stress periods.

Effects on Crop Production

Significant increases in infiltration, decreases in evaporation from soils, increased water-holding capacity, increased snow catch, and deeper rooting associated with no-tillage will all help increase the units of crop produced per unit of precipitation received (Langdale et al. 1994).

Higher residual-organic-matter contents in soil also increase the general fertility and productive capacity of soils. This residual organic matter acts as a "bank" into which nutrients may be absorbed in times of surplus and from which

nutrients may be withdrawn when leaching due to rainfall or irrigation has removed most of the soluble and mobile nutrients (especially nitrates) from the soil. Although prolonged nutrient deficiency should be alleviated with fertilizer nitrogen, temporary deficiencies of nitrates will not reduce crop growth nearly as much in soils with high organic-matter contents, where microorganisms are slowly and continually releasing nitrogen from the “bank.”

The residual organic matter, derived from plants, includes most of the elements essential for crop production, and its slow decay provides crops with a limited but continuing source of these elements. The slow decomposition of this organic matter also furnishes a host of organic molecules or fragments that can act as carriers, to mobilize micronutrients absorbed on the soil minerals and enable them to reach the roots. Tillage accelerates the rate at which nutrients from both the crop residues and residual soil organic matter are mineralized or made available to the crops. If the crop is not ready to use the nitrates, they are at risk of being leached out of the crop root zone by rain. In many respects, the tillage of soil is like stirring the coals, putting in kindling, and opening the draft on a coal and wood stove: Tilling accelerates the rate of oxidation of the organic matter, liberating its components quickly to the surrounding environment.

Organic matter also darkens soils. Soils appear dark because they are absorbing more of the sun’s radiation. Soils that absorb more of the sun’s radiation become warmer. If the soils remain covered with crop residues (which reflect more of the radiation), they will stay cooler; this decreases the plant growth in the cool early spring, but may be better for crops in the late spring or early summer before canopy has covered the soil.

Long-term cover with residues will darken the surface of most soils so that when they are uncovered, they look more like the black chernozems of the Midwest. If the farmer has darkened his soils with long-term residue cover and finds that crop growth is facilitated during the spring by higher temperatures, he can use equipment on his tool bars to move the residue off the seed rows before or at the time of planting. Such removal may enable the farmer to continue the effective use of conventional seeders, if he cannot afford to purchase a no-till seeder at that time.

Cooler spring temperatures under mulches, outbreaks of disease and insects in monoculture, and occasional lapses in weed control have the potential to reduce yields on fields under some conditions where all residues have been left on the surface, compared to yields on clean tilled soils. However, on most soils (fig. 19), the long-term benefits of no-till (including increased residual-organic-matter content, improved water-use efficiency, and possibly increased experience of the no-till manager) generally result in greater productivity than do tilled fields as time progresses.

Effects on Erosion Control

As soon as any soil receives residue cover, substantial erosion control is achieved (Langdale et al. 1992a) due to (1) interception by the residues of raindrop impacts, slower surface sealing, and higher sustained infiltration; (2) ponding of water on the surface by crop residues, which causes wormhole cracks and other macropores in that section of soil to fill and become active avenues for infiltration; and (3) settlement of sediment in the temporarily ponded water (Langdale et al. 1994).

Refraining from tillage allows more time for long-term mineralogical processes to develop more strength (these processes are somewhat similar to those causing moist concrete to become stronger). In most soils, long-term no-till management increases the populations of earthworms and associated macropores, which in turn increase the infiltration and reduce the runoff and erosion. Long-term no-till causes major changes in the organic matter of the immediate surface soil so that the soil is much more resistant to slaking and aggregate disintegration and has higher infiltration rates.

Arguments For and Against Tillage

There are still several legitimate arguments for the limited tillage of soils, as follows:

- In some cases, the cost of a form of a nutrient (such as the anhydrous form of ammonia) is sufficiently lower than the cost of other sources, that it provides economic justification for the limited cultivation caused by the thin sharp knives or coulters used to incorporate it.
- Deep chiseling or paratilling of soils to help crop roots get past the restricting layers appears to benefit yields in some areas. However, Langdale et al. (1992b) found that after 10 yr of no-till and winter cover crops, the layers became less restrictive and the chiseling was no longer necessary.
- Ridge-till or row-till equipment can push residues off the strip in which row crops are to be planted, allowing the use of conventional planting equipment and also warming the soil to accelerate early growth of some crops. (This may apply to corn in New York and cotton in northern Alabama.)
- Under some climatic conditions, weed and grain seeds need a light soil cover to help them germinate so they can all be killed by one herbicide application before a long fallow season or before planting the next crop.
- During the initial 2 or 3 yr of no-till, before sufficient soil cohesion has developed to support equipment weight, the soil may become so compacted and rutted when harvest has

to be conducted during wet weather that tillage is necessary to improve the compaction and smooth the surface.

- Existing regulations in some states or regions require the burial of specific wastes and crop residues to control specific insects and diseases.

Weed management scientists, recognizing the ability of several perennials (such as hemp dogbane, common pokeweed, curly dock, bigroot morning-glory, and trumpet-creeper) to survive many chemical treatments, commonly recommend tillage when these persistent perennials become entrenched. Many long-term no-till farmers recognize the value of maintaining high organic-matter contents in the first few millimeters of soil, of crop residues on the soil surface, and of keeping the macropores and soil structure intact; so these farmers are strongly averse to even occasional tillage operations.

Having gone through the no-till soil-building process and experiencing long-term yield improvements of the type indicated in figure 19, many long-term no-tillers are concerned that a tillage operation could set them back several years on such response curves. They are convinced that such a setback could cost them hundreds of dollars per acre and are consequently determined to control their weeds without tillage.

These no-tillers consider the recognition of weeds in the early vegetative stage as a first prerequisite to weed control. They study the growth habits of weeds and learn when each is likely to appear and when it is most vulnerable to herbicide control. They scout their fields as needed to identify these unwelcome intruders and then plan their termination.

Long-term no-tillers also study the means by which troublesome weeds enter their fields. Equipment (for seeding, fertilizing, and harvesting) is inspected and cleaned as needed before they are brought onto “clean” fields. If animals are allowed to enter and graze crop residues in a “clean” field, they are kept out of weed-infested fields and hay for at least 2 days before their entry, because many weed seeds ingested by cattle are viable when they emerge from the digestive tracts. These no-tillers identify neighborhood sources of problems; then to eliminate these sources, they offer assistance to or bring social pressures to bear on the owners of the infested fields.

Long-term tillers plead for the updating of lists of noxious weeds, to include those that are and will be problems in current and future crop-production systems. Updating of these lists would facilitate the development of community-wide programs to enforce the control of current and emerging weed problems.

Perceiving that major economic loss will result from tillage, long-term no-tillers are willing to invest in alternative

methods of perennial weed control. These methods include choices of short-season crops and their varieties that can be planted late or harvested early and that will leave the remainder of the season open for use of “burndown” chemicals to control the persistent weeds. Short-stature crops are also selected so that tall-stature weeds (such as hemp dogbane and common pokeweed) can be rope wicked with glyphosate (such as Roundup), a low-cost operation. On sparse stands of pokeweed, trees, and shrubs, the long-term no-tillers commonly train hired help to use spades and mattocks to remove extremely persistent and unwelcome plants. They argue the merits of hand removal rather than tillage to avoid the destructive effects of tillage on the near-surface organic matter and on the water-use efficiency of the whole field. They have concluded that the economics are sound.

One of the most economically critical factors in these considerations of highly erodible lands is the degree to which tillage will destroy soil cohesion, crop residue cover, and erosion control, as computed by the guidelines and equations that the Natural Resource Conservation Service technician must follow. The economic consequences of failure to be in conservation compliance will be devastating for most farmers who are enrolled in the Government programs. Consultation with these technicians (who have been saddled by our laws with making decisions on conservation compliance) may help farmers avoid the loss of both erosion control and crop support payments. One moldboard plowing can result in the disruption of continuity of macropores and the biological oxidation of as much organic matter from a soil as can be accumulated during several years of high-residue no-till management. Consequently, the expected benefits of moldboard plowing must be large enough to justify it. When tillage is necessary, other types that cause less oxidation should be considered.

Effects of Reducing Tillage on the Environment

Concern has been expressed by some public sectors that the long-term use of herbicides rather than tillage for weed control will add manufactured chemicals to and thereby degrade our soil, air, and water. A broad-scale survey by Bull et al. (1993) indicated that about equal amounts of herbicides were being used on tilled and no-till systems growing corn. The similar amounts of herbicides used indicate that most farmers recognize that herbicides are often the most cost-effective means of weed control, even when tillage equipment is available. In 1990, the average herbicide use on no-till soybeans was about 56 percent higher than that on conventionally tilled soybeans. By 1992, the average was only about 13 percent more herbicide use on no-till than on tilled soybeans. In 1994, long-term no-tillers said they were using less herbicide than when they started no-till management and often even less than when

they were tilling. Since no-till was almost doubling every 3 yr during 1987–93, 50 percent of the no-till farmers reported by Bull et al. (1993) were still in the initial 3-yr learning stage, and only 25 percent of the no-till farmers had had 6 or more years of no-till experience. Consequently, we anticipate that the amounts of herbicide used in no-till farming will continue to decline.

Another factor that will play a significant role in the herbicide contamination of our water is the relative use of soil-incorporated (preemergence) herbicides versus direct-contact (postemergence) herbicides. Preemergence herbicides are the more common choice of conventional tillers. The chemicals that function best as preemergence herbicides are those that are mobile (not adsorbed) in the soil and persist for long periods of time before they degrade. On the other hand, many of the postemergence herbicides, which are becoming the major choice in no-till management, are sprayed directly on the weeds; are strongly adsorbed to soil if they miss their target; and are rapidly hydrolyzed, biologically decomposed, or immobilized when they contact the soil.

The benefits of reduced tillage in terms of keeping topsoil on our land and out of our streambeds, reservoirs, and lakes are obvious. Where no-till increases infiltration rates, the reduced flood damage and the increased groundwater recharge and base stream flows will improve our environment.

On monitored watersheds on soils where, under conventional tillage, surface sealing has caused runoff of 10–30 percent of precipitation, long-term no-till has increased the infiltration to the degree that runoff is practically negligible. As water runs off land surfaces, it carries feces from domestic and wild animals, disease organisms, and a host of organic compounds, of which over 99 percent are of natural origin and less than 1 percent of manufactured origin. Surface runoff that enters our reservoirs is commonly so laden with contaminants that standard rapid filtration through sand filters in treatment plants does not remove all of them. Chlorination is commonly required to kill the pathogens before these sand-filtered surface waters can be used for drinking. But chlorination of humic acids and natural organic compounds can increase their carcinogenicity.

In some sandy shallow soils in which macropores are continuous from the surface to the aquifer, similarly incomplete filtration of percolating waters can occur. However, in most soils in the United States, these macropores are not continuous to the aquifer; they disappear in the finer textured subsoils. When surface residues, earthworm channels, and so forth enable all the precipitation to enter these soils, the pathogens and other organic compounds are filtered out of the water that percolates slowly down through the fine materials. In this way, the water that

arrives at aquifers is generally of good drinking quality. In these deep medium-textured soils, management that diverts runoff to infiltration is beneficial to water quality.

In general, refraining from tillage will enhance the organic matter, water-use efficiency, and overall productivity of our soils. There are still problems to be solved to optimize the application of no-till to many soil-climate-crop systems. Solutions to those problems are being rapidly developed by manufacturers, scientists, and innovative farmers. Long-term benefits derived from no-till are an investment that will pay long-term dividends for ourselves and for future generations.

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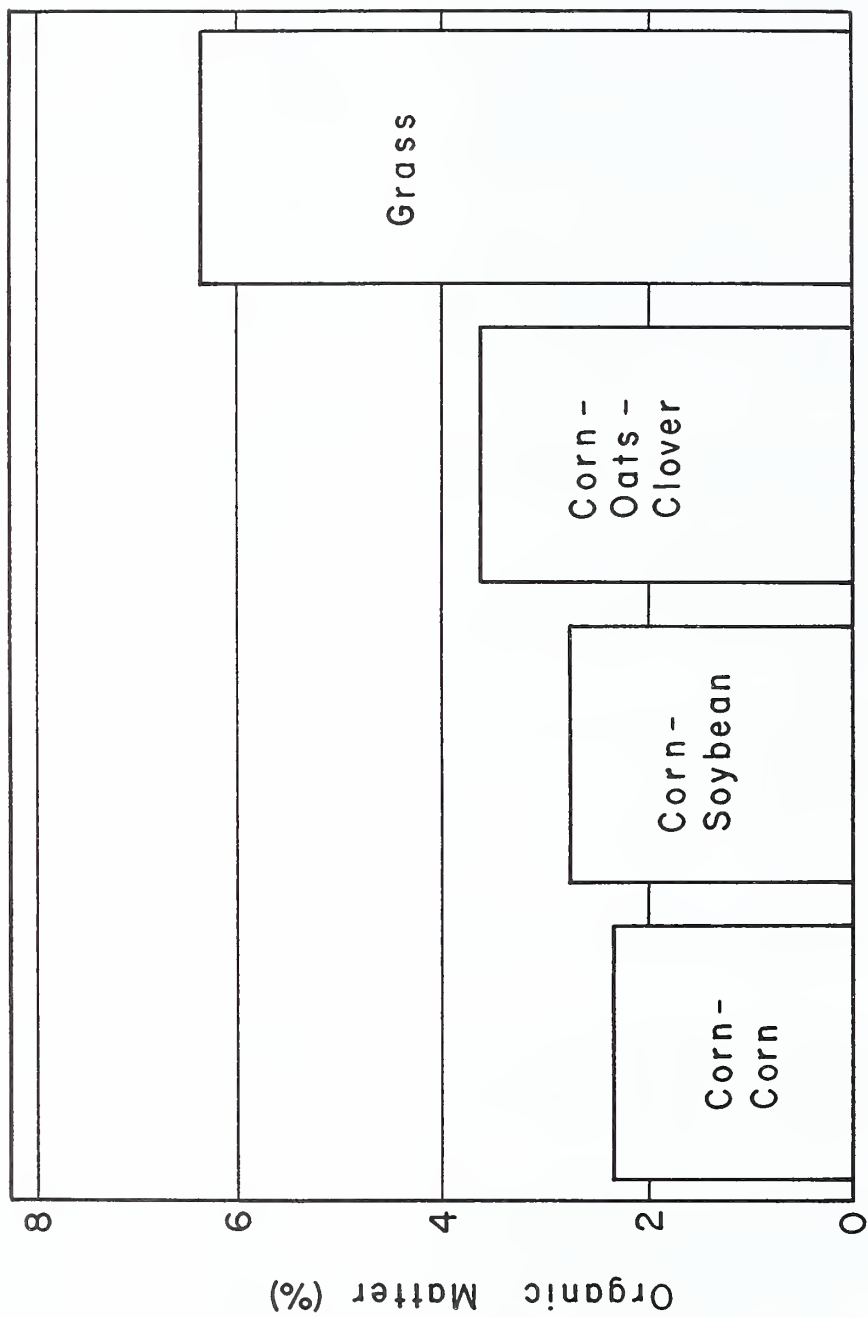


Figure 13. Percentage of organic matter in plowed soils after more than 100 yr in various rotations compared with percentage in untilled soil still in grass

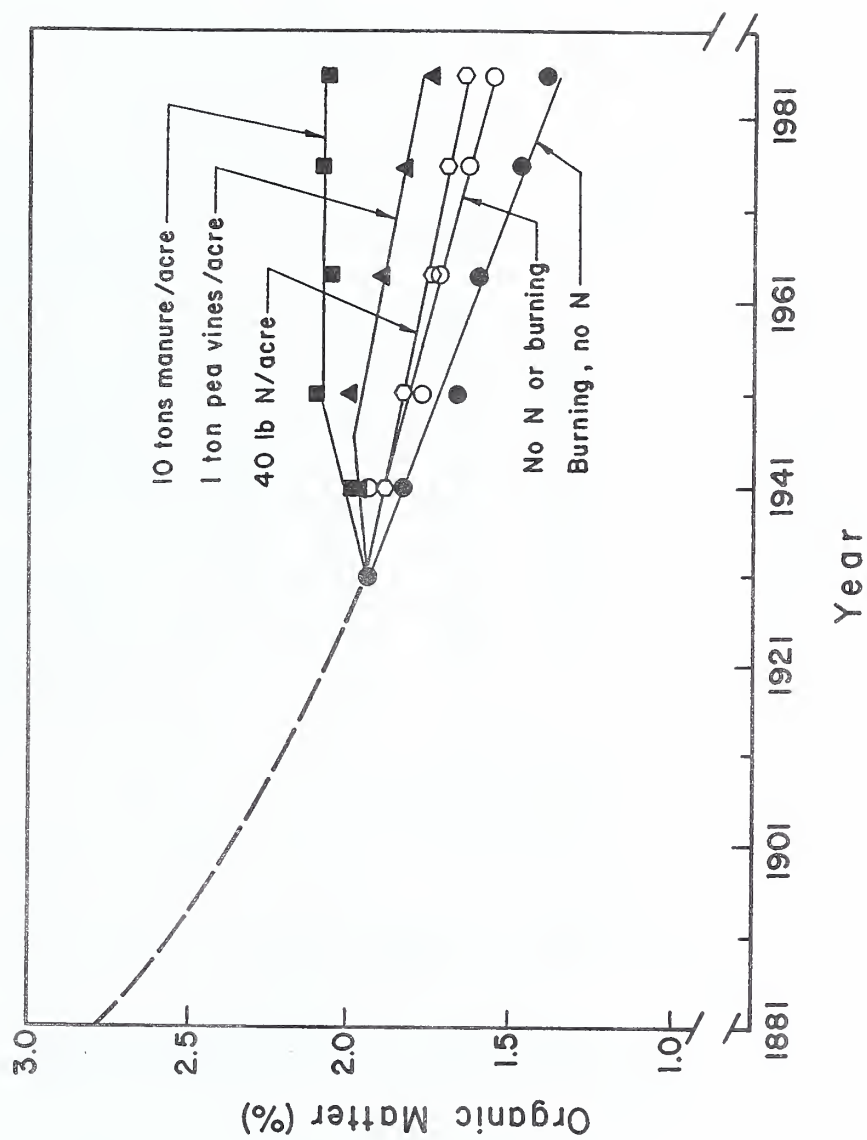


Figure 14. Effect of management practices on long-term changes in organic matter in top 30 cm of a Haploxeroll soil in Oregon. Source: Rasmussen et al. 1989.

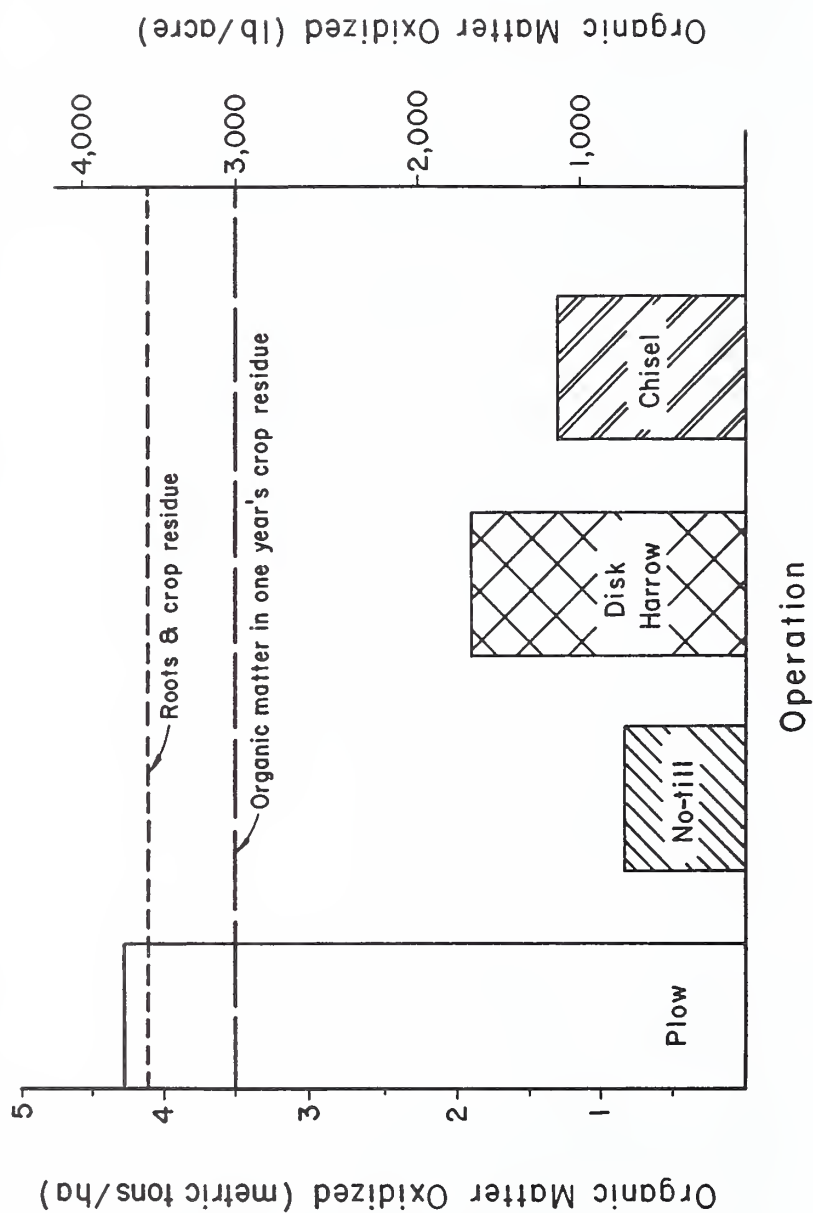


Figure 15. Organic matter oxidized in 19 days in September following various tillage operations on wheat stubble in Morris, MN

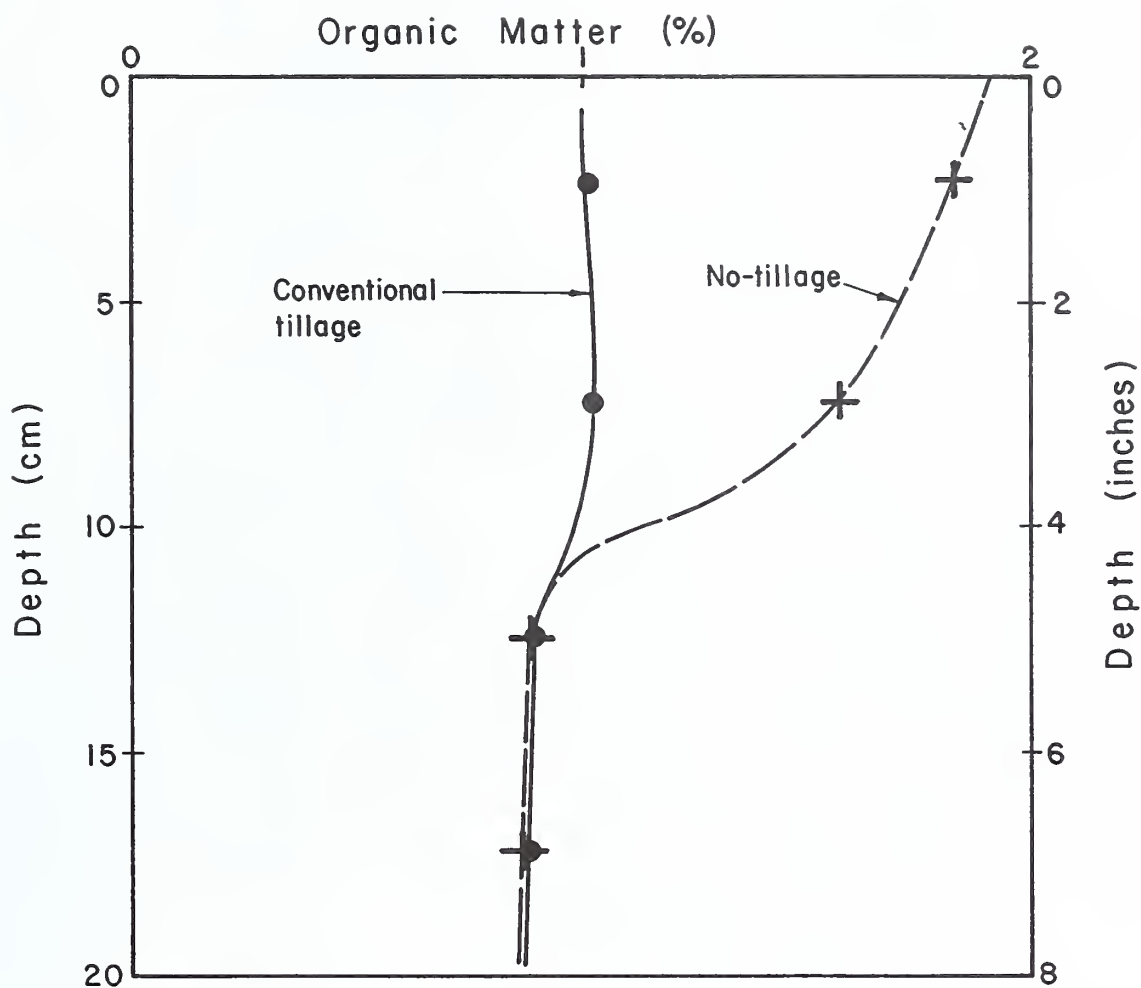


Figure 16. Comparison of organic-matter content at various soil depths after 10 yr of a conventionally tilled and a no-tilled corn-wheat-soybean-wheat rotation in Crossville, AL

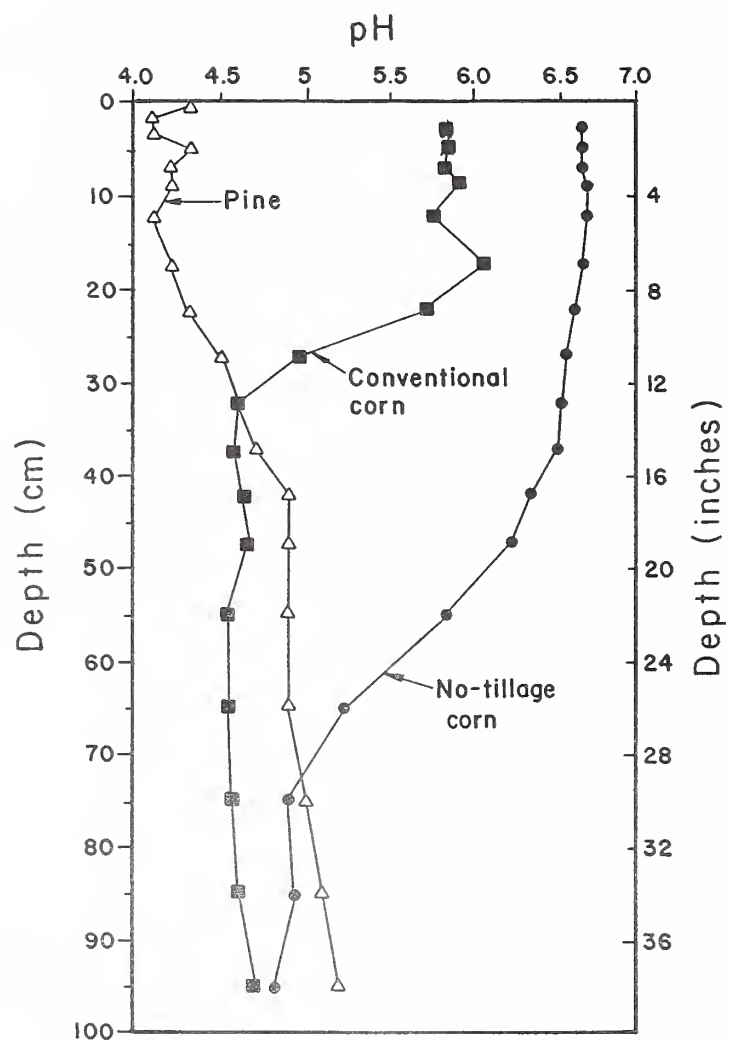


Figure 17. Effect of conventional and no-till managements of corn on soil pH at various depths. Source: Edwards et al. 1988.

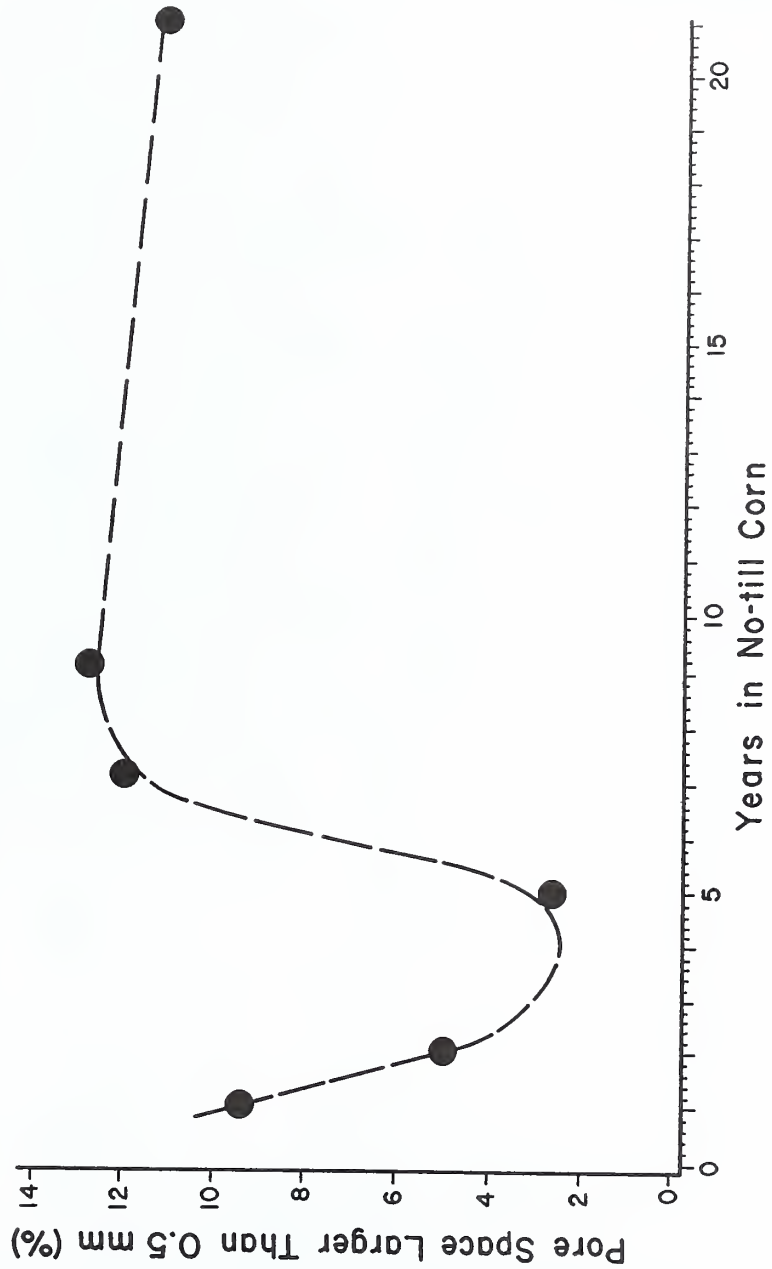


Figure 18. Changes in surface pores larger than 0.5-mm diameter after beginning no-till management in Coshocton, OH.
Source: Norton and Schroeder 1987.

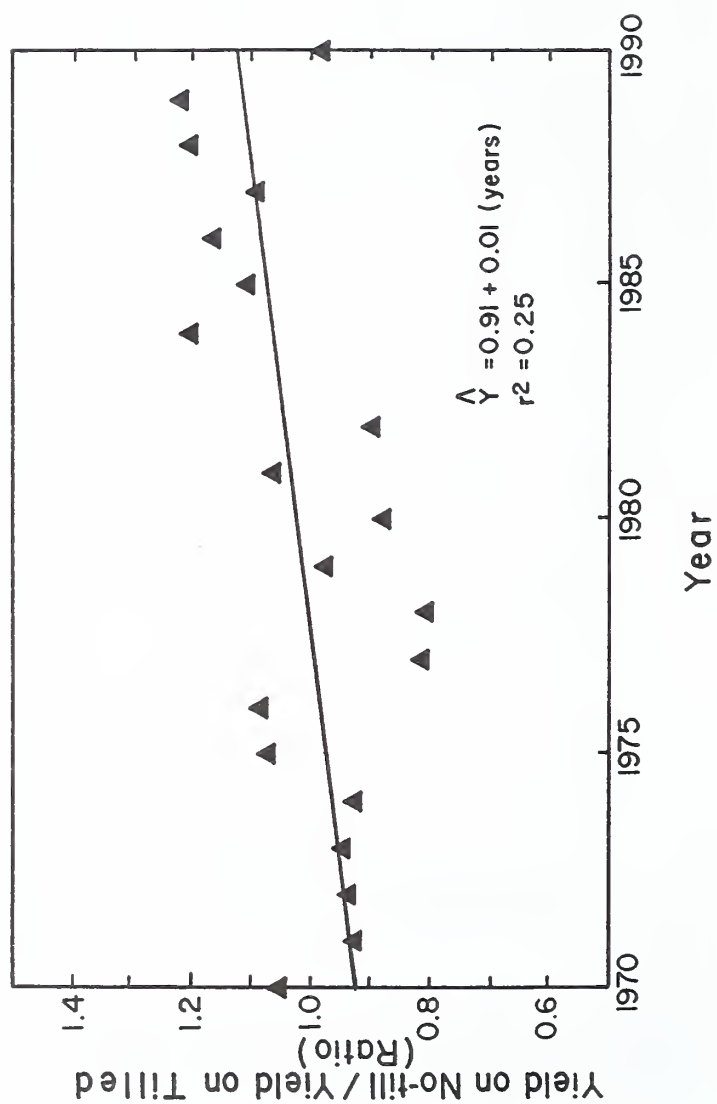


Figure 19. Long-term trends in corn yields under no-till compared to those under tilled management. Adapted from Ismail et al. 1994.



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MAJOR LAND RESOURCE AREAS OF THE NORTHEAST AND APPALACHIAN REGION (L, N, R, S)

L**LAKE STATES FRUIT, TRUCK, AND DAIRY REGION**

- 95A Northeastern Wisconsin Drift Plain
- 95B Southern Wisconsin and Northern Illinois Drift Plain
- 96 Western Michigan and Northeastern Wisconsin Fruit Belt
- 97 Southwestern Michigan Fruit and Truck Belt
- 98 Southern Michigan and Northern Indiana Drift Plain
- 99 Erie-Huron Lake Plain
- 100 Erie Fruit and Truck Area
- 101 Ontario Plain and Finger Lakes Region

E**EAST AND CENTRAL FARMING AND FOREST REGION**

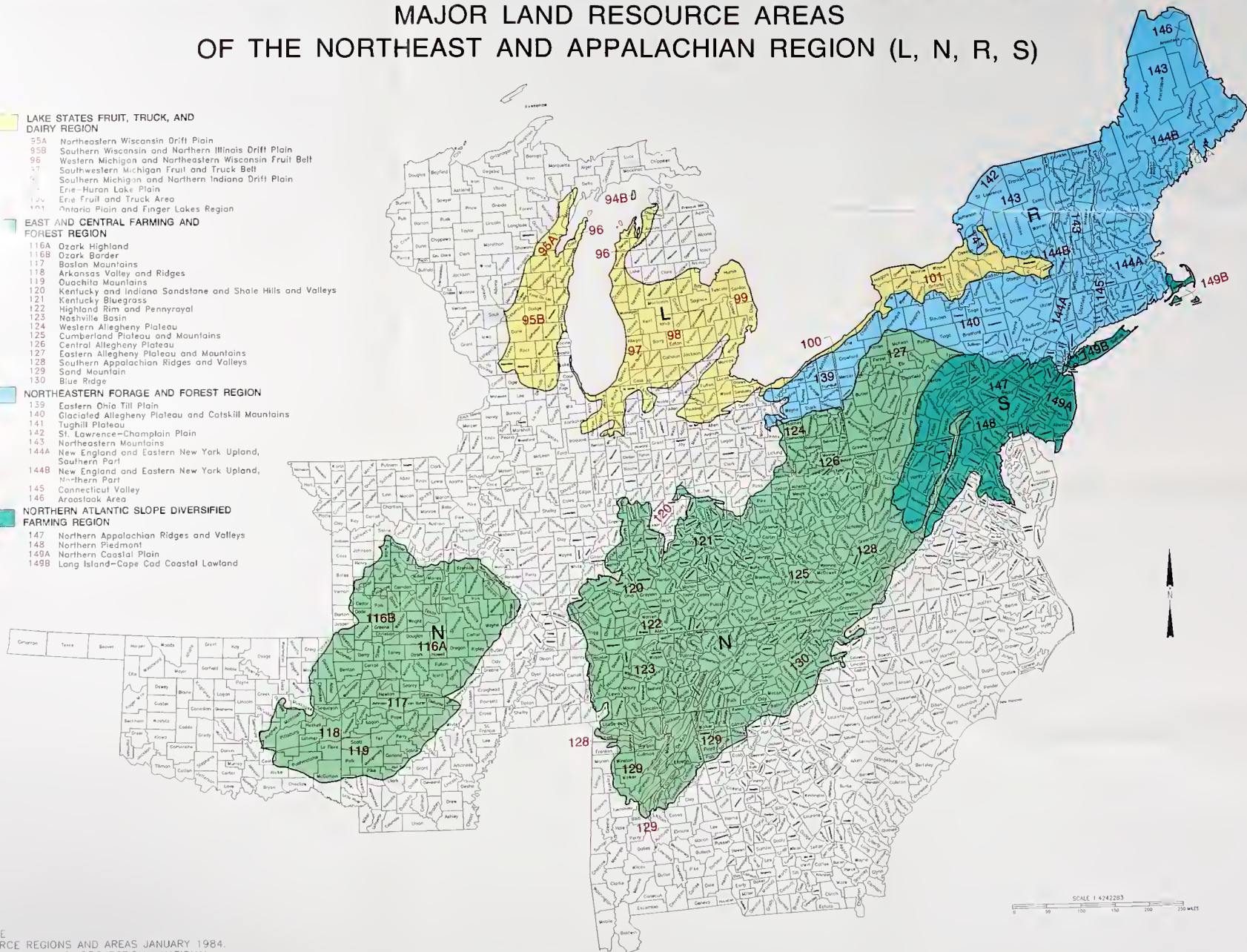
- 116A Ozark Highland
- 116B Ozark Border
- 117 Boston Mountains
- 118 Arkansas Valley and Ridges
- 119 Ouachita Mountains
- 120 Kentucky and Indiana Sandstone and Shale Hills and Valleys
- 121 Kentucky Bluegrass
- 122 Highland Rim and Pennyroyal
- 123 Nashville Basin
- 124 Western Allegheny Plateau
- 125 Cumberland Plateau and Mountains
- 126 Central Allegheny Plateau
- 127 Eastern Allegheny Plateau and Mountains
- 128 Southern Appalachian Ridges and Valleys
- 129 Sand Mountain
- 130 Blue Ridge

R**NORTHEASTERN FORAGE AND FOREST REGION**

- 139 Eastern Ohio Till Plain
- 140 Glaciated Allegheny Plateau and Catskill Mountains
- 141 Tugbill Plateau
- 142 St. Lawrence-Champlain Plain
- 143 Northeastern Mountains
- 144A New England and Eastern New York Upland, Southern Part
- 144B New England and Eastern New York Upland, Northern Part
- 145 Connecticut Valley
- 146 Aroostook Area

S**NORTHERN ATLANTIC SLOPE DIVERSIFIED FARMING REGION**

- 147 Northern Appalachian Ridges and Valleys
- 148 Northern Piedmont
- 149A Northern Coastal Plain
- 149B Long Island-Cape Cod Coastal Lowland





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